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A FEASIBILITY STUDY OF THE COLLECTION OF UNSCHEDULED MAINTENANCE DATA USING STATISTICAL SAMPLING TECHNIQUES

THESIS

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Captain, USAF

AFIT/GLM/LSM/85S-32

DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY
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Wright-Patterson Air Force Base, Ohio

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THESIS

Presented to the Faculty of the School of Systems and Logistics of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the

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Master of Science in Logistics Management

Robert A. Heinlein, B.E., M.B.A.

Captain, USAF

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Robert A. Heinlein

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Abstract

This study explores the feasibility of using statistical sampling techniques in lieu of a census to collect Air Force maintenance (MDC) data. A practical sampling methodology is identified and the sample size required to collect data with a specified degree of statistical precision is illustrated. The variable cost of MDC data collection and processing is also identified. Using the F-16A Fire Control System on the aircraft at one base as an example, the potential cost and effort savings resulting from sampling are evaluated.

The sampling concept is based on a simple random sample of aircraft, by serial number, with full data collected on all aircraft in the sample. The sampling plan is designed to estimate the base level monthly total unscheduled maintenance manhours at the two digit work unit code level, with 10 percent relative precision and 90 percent confidence. The methodology used to estimate the variable cost of collecting and processing MDC data records is limited to base and Air Force Logistics Command (AFLC)

levels. Base level costs considered are the opportunity cost of a maintenance technician's time to enter one MDC record into an automated system terminal, and the cost of computer processing and transmission of data to AFLC. AFLC costs considered are the machine time charges assessed against the D056 Product Performance System.

In the single system studied, the variability in monthly unscheduled manhours per aircraft was found to be high. The resulting sample size required to estimate manhours with the desired degree of statistical accuracy, based on the greatest observed variability in historical data, nearly represents a census. The variable cost of collecting and processing MDC data is significant. However, unless a sophisticated technique can be used to predict data variability and reduce the required sample size, the potential cost and effort savings resulting from sampling appear to be minimal.

A FEASIBILITY STUDY OF THE COLLECTION OF UNSCHEDULED MAINTENANCE DATA USING STATISTICAL SAMPLING TECHNIQUES

I. Introduction

General Issue

The Air Force Maintenance Data Collection (MDC) System has been the object of much criticism in numerous studies and reports during it's nearly thirty year history. The major complaints associated with MDC are that the system contains inaccurate and incomplete data; the voluminous data require a tremendous effort to collect and process; and the feedback of useful data to management at all levels is untimely and of questionable value and accuracy. In addition, the inability of field maintenance personnel to directly benefit from the data provides no incentive to collect accurate data. Questions have also been raised about the need to collect the volume of data currently processed by the system and whether the data meet the needs of MDC system users. Additionally, the MDC system does not provide adequate feedback of the type of data needed to accurately evaluate the reliability and maintainability (R & M) performance of fielded systems (25:343-345; 29:IV-24). The specific problems associated with the MDC system have been identified in several studies during the past decade (22:44-5Ø).

These problems are compounded by the use of MDC data in other logistics management information systems. For example, the Visibility and Management of Operating and Support Costs Program (VAMOSC), the Maintenance and Operational Data Access System (MODAS), and the Product Performance System (DO56) all receive data from the MDC system. Data provided by these systems are used to determine operating, support, and life cycle costs; to provide limited feedback on reliability and maintainability of fielded systems to the Air Force and defense contractors; and to develop cost and performance baselines used in the evaluation of new system acquisitions (12:2.1-2.2). In addition, MDC data are used to develop data bases for Logistics Composite Modeling (LCOM) simulations, the results of which are used to determine maintenance manpower requirements and authorizations (10). Needless to say, the effectiveness of decisions based in whole or in part on MDC data depends on the accuracy and timeliness of the data collection system.

The inability of the MDC system to provide adequate reliability and maintainability feedback data led to the development of an additional data system to support the F-16 System Program Office at Wright-Patterson AFB, Ohio (22:18). The F-16 Central Data System (CDS) was developed to automate the collection of reliability and maintainability data and to provide the capability to track and portray statistics and trends of this data for the F-16 and its avionics automatic test equipment.

In 1975, the Air Force began a test program, the Automated Maintenance System (AMS), designed to evaluate the automation of selected maintenance information and control processes and to establish the value of the concept for implementation throughout the Air Force (22:24). Among the automated processes was the on-line collection and retrieval of MDC data. The AMS system should virtually eliminate inaccurate and incomplete data collection, reduce the effort required to collect and process the high volume of MDC data, and provide timely access to and feedback of information needed to manage and control maintenance operations. The AMS system provides a feasible solution to many of the probems associated with the MDC system in the past. The success of the AMS test program led to a decision to test a similar system, the Core Automated Maintenance System (CAMS), at several Air Force bases during 1985. If the tests are successful, this system is planned to be installed at all bases as part of the current Air Force Phase IV computer upgrade program (21:16).

The Automated Maintenance System, and the subsequent implementation of the concept in CAMS, does not address two of the problems associated with the MDC system. It does not address the volume of data collected relative to it's usefulness as information, and it does not provide any improvement in the type of data needed to provide adequate feedback of reliability and maintainability information. The data elements and the volume in which they will be collected in the CAMS system remain virtually unchanged from the manual data collection process CAMS replaces (2:1.1). These two issues form the basis for this thesis study.

To address the first issue, it is necessary to evaluate methods of reducing the volume of data collected, while maintaining the ability to derive useful and reliable information from the data. The second issue requires an analysis of what additional data is needed, followed by a determination of a method of collecting it. If more MDC data are collected than useful, and less reliability and maintainability data are collected than needed, it should be possible to reduce the volume of MDC data collected and replace it with improved reliability and maintainability data.

The best known method of collecting a limited volume of data on a smaller number of items in order to provide information about a larger number of like items is statistical sampling. The most common uses of statistical sampling are in public opinion and election polling, in manufacturing quality control, and in the field of auditing. There are two known instances where sampling has been used to collect aircraft maintenance data. A 1976 contractor study, known as "Project REALMS: Recommendations to Enhance the Air Logistics Maintenance System," recommended the application of statistical sampling techniques and trained observers to gather manhour data (22:21). In 1978, based on the Project REALMS study, the Air Force Logistics Management Center (AFLMC) conducted a pilot study to test the collection of manhour data through the use of work sampling methods. The study concluded that the use of the proposed work sampling methods for routine data collection was impractical from an administrative standpoint (5:4-2). In addition, a 1979 Air Force Audit Agency report on the AFLMC pilot study, stated that the proposed sampling plan would not satisfy the data requirements of other information systems, and that the impact on other ongoing projects was not considered (1:7-9). The U. S. Army has successfully employed the use of sampling to collect maintenance data on equipment since 1970, and on aircraft since 1978 (19:1-2). The sampling conducted by the Army is purposive, rather than random sampling, which implies that the data collected may not be truly representative of the population. Purposive, or convenience sampling, means that the sample is not chosen at random, such that each element of the population stands an equal chance of being selected. Therefore, the properties of inferential statistics cannot be used with purposive sampling. The aircraft maintenance data collected by the Army is similar, although more detailed, than the data collected by the Air Force. The Army also collects routine operations data in conjunction with the maintenance data.

Considering the two previous uses of sampling to collect maintenance data; the improvements in information processing technology; and the need for better reliability and maintainability data, it is useful to re-evaluate the use of a sampling concept to collect MDC data. A reduction in the volume of MDC data collected could then be used to balance an increase in the quality of reliability and maintainability data collection.

Problem Statement

The data currently collected by the MDC system are unquestionably of some value in maintenance and logistics management; however, the volume of data collected and the expense incurred to collect it may be unnecessary to provide the information management derives from the data (22). For example, the Air Force currently collects and processes over 23 million MDC data records annually (23). A 1982 Air Force Logistics Management Center study estimated the average annual cost of computer paper, punch cards, keypunch machine maintenance, and keypunch personnel used to collect and process MDC data at over $9 million (6:6-7). Not included in this figure are the costs of the maintenance technician who collects the data, magnetic tape used to store data, telecommunications used to transmit data to headquarters, computer time used to process data, and management time used to supervise the data collection effort and correct errors. Yet the useful value of much of the MDC data currently collected and processed through management information systems is considered marginal by managers (22:16-20). A recent study of Air Force maintenance information systems conducted by the General Accounting Office (GAO) questioned the need to collect such a large volume of data if it is not of value to management (22:23).

A better method of providing field reliability and maintainability data collection and feedback is needed (29:IV-24). The collection of improved R&M data can be accomplished either by increasing the number of data elements collected, over and above that of the current MDC system, with increased cost and effort; or by reducing the volume of MDC data and using the effort and cost savings to collect additional data. It would be useful to determine if a method can be found of reducing the volume of MDC data collection while maintaining the level of information derived from the data.

Statistical sampling techniques have been used for decades to collect data on a smaller segment of a population and to infer from the sample some useful information about the total population. It might be possible to use statistical sampling techniques to collect aircraft maintenance failure and manhour data, from which inferences can be made about the behavior of an entire aircraft fleet. Sampling techniques may reduce the volume of current MDC data collected. This could permit the increased collection of better quality reliability and maintainability data without adding additional costs or increasing the data collection effort required by maintenance personnel. This study is concerned with evaluating the feasibility of using statistical sampling for this purpose.

Research Objectives

The overall objective of this research is to determine whether statistical sampling is a practical and feasible method of reducing the volume and cost of MDC data without losing any valuable information. If sampling methods can be used to collect failure and manhour data with an acceptable level of precision and a practical sample size, it should be possible to reduce the volume of data collected and processed. This would reduce the cost of data collection and processing; reduce the amount of unproductive time required to record, process, and analyze the data; and improve the quality, accuracy, and detail of the information collected. The cost and effort saved can then be used for other purposes.

MDC data are collected on both scheduled and unscheduled maintenance activities. Unscheduled maintenance MDC records account for nearly two thirds of all MDC data. Thus, a reduction in the volume of unscheduled maintenance documentation through the use of statistical sampling represents the greatest potential for savings. Therefore, this study will only be concerned with unscheduled maintenance data. The feasibility of applying sampling concepts to the collection of unscheduled maintenance data will be evaluated against two main criteria:

a. Can the sampling scheme be practically controlled and administered in the field without any major changes in the way the data is currently collected and subsequently used in management information systems?

b. Can the use of sampling significantly reduce the costs associated with the collection and processing of MDC data?

Four subordinate objectives support the overall thesis objective:

a. Develop a practical, reliable, and representative sampling scheme that can be easily implemented in the field.

b. Illustrate the precision that can be obtained using the sampling scheme on selected MDC data and determine if the sample size required to attain this precision is practical for routine data collection.

c. Address the cost of data collection compared to the difference in information obtained by census and sampling.

d. Evaluate the impact of sampling on the data that would be used by LCOM, VAMOSC, and the Product Performance System.

Research Questions

The following questions were developed to guide the research effort:

1. What sampling plan(s) can best be applied to the collection of aircraft failure and maintenance manhour data to provide the same type of information to users of the MDC data?

2. What degree of precision can be obtained by sampling and how large must the sample size be?

3. How can the sample data be used and related to the entire population to obtain information such as Maintenance Manhours per Flying Hour (MM/FH) and Mean Time Between Maintenance (MTBM)?

4. Will sampling provide significant cost savings over the current census data collection methods?

5. What is the impact of the use of sample data on LCOM, VAMOSC, and the Product Performance System?

6. How can sampling be practically administered and controlled in he field?

II. Literature Review

Introduction

The Air Force Maintenance Data Collection System (MDC) has been in use for almost 30 years. During that period, many other information systems have been developed which use data supplied by the MDC system to varying degrees. MDC data are used by over a dozen logistics management information systems and are supplied to over 30 defense contractors and other Air Force agencies. Considering the extensive use of MDC data, any change in the data collection process can have a major impact on many users of MDC data. Since this research on the use of sampling to collect MDC data represents such a change, it is necessary to examine the impacts of a sampling concept on the users of MDC data.

This literature review provides an understanding of the MDC system and the uses of MDC data at all levels. It focuses on the past and present attempts to use sampling concepts to collect maintenance data.

Maintenance Data Collection System

Historical Perspective. The Air Force began the collection of data on base level maintenance activities through the MDC system in 1958. Prior to that time, maintenance activities were documented manually, in an unstructured narrative description, on Unsatisfactory Reports (URs). Clark and Badalmente describe the evolution of the MDC system.

They state that because the URs were unstructured and non-standardized, it was difficult to perform a meaningful analysis of unfavorable maintenance problems. This was compounded by a belief that only eight to ten percent of the equipment failures associated with potential problems were being reported (8:6-7). Badalmente and Clark reported that there was concern that decisions might be made incorrectly on such a small sample of data, and that there was equal concern that the means to assess equipment reliability across the inventory did not exist. In addition, Air Force management wanted a systematic method of establishing, adjusting, and justifying manpower requirements to Congress. To satisfy these requirements, the MDC system was ultimately established with a 100 percent reporting requirement. The mandatory reporting was designed to replace the URs with a set of coded data for analysis of unsatisfactory equipment performance (8:6-7).

The continued improvements in computer technology provided another step in the MDC evolutionary process. In 1966, the development of the Maintenance Management Information and Control System (MMICS) was begun with the purpose of providing an automated system for maintenance management. Development of the system continued in stages throughout the late 1960s and early 1970s. It was tested and approved for initial implementation in 1973. The AFTO Form 349, still in use today, was developed in 1968 to provide a data collection and control instrument more amenable to the evolving MMICS system than those previously used (8:9). The state-of-the-art computers in use during the MMICS development relied strictly on punch cards and magnetic tape for data processing. Accordingly, the procedures for collecting and processing MDC data were designed to accommodate the technology available at the time. The MDC and MMICS systems in use today have remained virtually the same since their original development.

Over the past several decades, management has questioned the MDC system reporting concepts, specifically the need to collect census data. In 1969, the Air Force Logistics Command (AFLC) and the Strategic Air Command (SAC) conducted a test of a limited reporting concept, to determine if census data was really necessary. The limited reporting concept resulted in a loss of some failure data considered essential by AFLC. The limited reporting concept was discontinued, and census data collection was retained (8:8-9). In 1973, an Air Staff and Major Command team studied the uses of maintenance data during Project Rivet Rally to determine the information needs of MDC users. The study concluded that the users needed more information than they currently received. However, this study produced no changes in the maintenance data reporting concepts (8:9). In 1976, a contractor study, entitled "Project REALMS: Recommendations to Enhance the Air Logistics System," was conducted to determine whether sampling techniques could be used to collect manhour and equipment reliability data (1:1). The study report recommended the use of statistical sampling methods and trained observers to gather manhour data (22:21). In 1977, the Air Force issued a Program Management Directive (PMD) tasking the Air Force Logistics Management Center (AFLMC) to design and conduct a pilot test of a modified MDC system as outlined in the study report. The objectives of the pilot test were to answer questions raised about the technical aspects and cost effectiveness of sampling and to assess the impact of the contractor's recommendations (22:21-22). The conclusion reached as a result of the pilot study was that sampling methods were technically feasible; however, they were neither practical nor cost-effective to administer (5:4.2). No changes to the MDC system or reporting concepts were made as a result of the Project REALMS and MDC Modification Project studies. Also in 1977, an Air Staff evaluation team studied the paperwork impact of various proposed methods of reducing MDC data collection. This study considered the elimination of off-shore reporting and support general documentation in the MDC system. The study led to a 1978 joint recommendation by the Deputy Assistant Secretary of the Air Force for Logistics and the Deputy for Productivity Management that engineered labor time standards be used as a way to reduce documentation and increase productivity. In response, HQ USAF/MPM and LEY agreed to pursue the development of job standards for highly repetitive or manhour intensive tasks in the support general area, in lieu of the detailed reporting of every task by individual technicians (22:22). The use of job standards for support general tasks proved to be successful in reducing MDC documentation; as a result, job standards for support general tasks are routinely used today (12:7.1).

Since the late 1970s, the Air Force has been attempting to update its computer resources to take advantage of current technology that was not yet available when the MMICS system was developed. In 1975, the Air Force began a test of an Automated Maintenance System (AMS) with the C-5A at Dover AFB, DE. The AMS is designed around the Malfunction Analysis Detection and Recording System (MADARS) onboard the C-5 and it's associated Ground Processing System (GPS). The AMS provides the maintenance manager with on-line, real time data input and retrieval capability. These features are designed to eliminate inaccurate data input, improve management access to useful and current information, reduce paperwork, and improve maintenance efficiency and effectiveness (22:24-30). The AMS test demonstrated the benefits of state-of-the-art computer technology to the maintenance management arena. Since 1975, there have been attempts to implement the AMS system concept Air Force wide. However, funding restrictions delayed this initiative until the Air Force began implementation of the Phase IV computer upgrade program in the mid 1980s. An AMS derivative, the Core Automated Maintenance System (CAMS), was developed in conjunction with the Phase IV program and is currently being tested at three bases. If the tests are successful, the CAMS will be implemented throughout the Air Force beginning in April 1986 (21:16). The CAMS system is designed around the original MMICS and the AMS system concepts. As developed, it does not change the maintenance reporting concepts that have been used since the MDC system was originally designed.

Purposes and Uses of MDC Data

The Maintenance Data Collection System was developed to provide management with the means to assess equipment reliability and the effectiveness of the Air Force maintenance effort. These two broad categories can be directly related to a significant portion of the Air Force budget and to the readiness and sustainability of our combat forces. Effectiveness is measured through the MDC system in the form of personnel productivity and operating and support costs. Reliability is measured as a function of the number of failures reported through the MDC system and the flying or operating hours of aircraft or equipment. Maintainability can be measured as a function of the manhours required to make repairs. The MDC data are used as a measure of the reliability and maintainability of current weapon systems. Reliability and maintainability are key factors that influence weapon system design, effectiveness, logistic support requirements, and life cycle costs. Collection of maintenance data is intended to provide a critical information feedback loop to management at all levels, in both the acquisition and logistics communities.

MDC data are intended for use by management at both the base level and by other commands and agencies. At base level, the intended use of the data is to provide information feedback to base managers and supervisors for controlling the maintenance operation. Other commands and agencies use the data as feedback to managers on the performance and support requirements of Air Force weapon systems and equipment (12:1.3).

Base Level Uses of MDC Data. MDC data are intended to provide base level managers and supervisors, directly or indirectly, with the following types of information to effectively manage their operations (12:1.3):

1. Production information about the type of work per formed, units performing the work, and equipment on which the work is performed.
2. Equipment maintenance schedules.
3. Direct and indirect labor expenditures.
4. Equipment failure and discrepancy information.
5. Status of equipment modifications.
6. Cost of civilian and military labor.
7. Cost of productive direct and indirect labor hours.
8. Cost to maintain aircraft, engines, and equipment.
9. Reimbursement for maintenance on transient aircraft.

__AFLC Uses of MDC Data__. The Air Force Logistics Command uses the MDC data internally in its logistics management functions to (12:1.4):

1. Identify reliability and maintainability problems on Air Force equipment.
2. Establish priorities for product improvements and modifications.
3. Keep track of modifications and evaluate their effectiveness.
4. Validate inspections and time change requirements and intervals.
5. Identify safety deficiencies and monitor corrective action.
6. Validate and adjust calibration intervals.
7. Validate spares requirements.
8. Identify programmed depot maintenance requirements.
9. Compile fleet estimates of maintenance manhours per flying hour (MH/FH).
10. Evaluate unsatisfactory material reports and modification proposals from other commands and industry.
11. Recover costs of depot maintenance performed for other commands and agencies.

__Other Uses of MDC Data__. In addition to it's own internal uses of MDC data, AFLC provides MDC data to industry and the Air Force Systems Command. The data are used to relate the performance and support requirements of current inventory equipment to the development of new weapon systems. Data are also provided to Headquarters USAF, other services, and the major commands (MAJCOMS). MDC data are used by the MAJCOMS to determine the status of equipment modifications;

by HQ/USAF and the MAJCOMS for determining and validating manpower requirements; and by HQ/USAF Accounting and Finance to determine the cost of base level maintenance operations (12:1.5).

MDC System Description

The Maintenance Data Collection System can best be understood by examining the types of maintenance data collected, the data collection process, and the data processing procedures. The following sections are mainly provided for those readers who are unfamiliar with the MDC system.

Coded Maintenance Data. All maintenance data are reported through the use of alpha-numeric codes designed to simplify and standardize the recording procedures; to provide the required information with a minimum amount of writing on the recording form; and to minimize the computer processing and storage requirements (12:3.1). The types of codes used and their functions are (12:4.1-4.10):

1. Job Control Number (JCN): The JCN is a unique seven character number used to control and identify authorized maintenance jobs. This number provides a means of tying together all maintenance actions taken, labor hours expended, and parts replaced in satisfying a specific maintenance discrepancy.

2. Work Center Code. The workcenter code consists of five characters and is used to identify the organization to which maintenance personnel are assigned or dispatched.

3. <u>Identification Number (ID)</u>. The ID number consists of six characters and is used to identify aircraft or equipment upon which work is performed or from which the item was removed.

4. <u>Type Maintenance Code</u>. The type maintenance code consists of one character, which is used to identify the type of maintenance work being accomplished. Examples of type maintenance are preflight, inspection, or unscheduled maintenance.

5. <u>Work Unit Code (WUC)</u>. The WUC is a five character code used to identify the systems, subsystems, or components upon which maintenance is required or performed. Work unit codes are designed as quick reference numbers to identify system, subsystem and component relationships. This provides a standard method of sorting maintenance data and of summarizing different levels of detail. Work unit codes provide the capability to utilize data in maintenance or engineering programs by multiple systems, individual systems, subsystems, or components within each weapon or support system.

6. <u>Action Taken Code</u>. The action taken code consists of one character used to identify the actions taken by the technician in the process of performing maintenance. Common examples of actions taken are troubleshooting, remove and replace, and bench check.

7. <u>When Discovered Code</u>. This one character code is used to identify when a defect requiring maintenance was discovered in terms of equipment operation or maintenance activity. For example, the defect might have been noted during flight, preflight, or major inspection. Discrepancies which cause a mission abort have distinct codes to identify the operational impact of the fault.

8. <u>Category of Labor</u>. This data element is used to distinguish between types of manhour expenditures, such as military or civilian, regular or overtime, and direct or indirect labor.

9. <u>Employee Number</u>. This number is a five digit code used to identify the individual technician who performed the maintenance action.

<u>Logic of Data Elements</u>. The coded data supplied by the maintenance technician can be converted into meaningful information for analysis purposes. The data are intended to provide a complete record of all activities required as a result of a particular discrepancy. For a given discrepancy, it is possible to determine which aircraft was involved; which system components and parts malfunctioned; what the malfunction was; when it was discovered; what actions were required to make repairs; who was involved in the repair; which shop the technician was assigned to; and how many manhours were required to make the repair. It is also possible to recreate a complete maintenance history for a

particular airframe for a particular time period, or to determine the number of failures of a specific type of component on a particular aircraft. The MDC system has the potential to provide a great deal of useful information for detailed analysis at the micro level.

The MDC system is also designed to provide data at the macro level. At this level there is less interest in specific information about a particular airframe, and more interest in base and fleet level summary information. For example, the MDC data can provide the total number of failures for a specific type of component and the total manhours required to maintain or repair the component. This information is used in the determination of support costs and spares requirements, and to validate manpower requirements.

Data Collection. There are currently two methods of data collection used in the Air Force. Manual data collection on paper forms, with data entry by punch cards, is still the most widely used method as of this writing. One base, testing an automated maintenance system concept, collects data manually, with real time data entry into a computer terminal. The trend in the future, with the Core Automated Maintenance System, will be the simultaneous data collection and entry by the maintenance technician through a computer terminal.

Data Processing and Transmission. Maintenance data are processed at the base level and stored on magnetic tape.

The data are transmitted monthly to the Air Force Logistics Command Headquarters either through electronic communication links or by physically sending a copy of the tape through the mail. The data from all bases are then processed by the D056 Product Performance System. AFLC provides the monthly data to the MAJCOMS, air logistics centers, and other users. The data are also supplied at various times to a number of other AFLC information systems, such as the Visibility and Management of Operating and Support Costs (VAMOSC II) system (24).

In addition to the transmission of data to AFLC, base level data tapes are used by MAJCOM management and manpower engineering teams in their determination of manpower requirements using the LCOM model. These tapes are not transmitted on a regular basis because manpower requirements for a specific base are not continuously evaluated. When the manpower requirements determination is performed for a particular base, tapes containing maintenance data for the past year are sent from the base to the command or agency performing the manpower analysis (7:3.4).

Use of MDC Data in Other Information Systems

Although the data provided by the MDC system are used by numerous management information systems and many other individual users, the Product Performance System (D056), the Visibility and Management of Operating and Support Costs (VAMOSC) system, and the Logistics Composite Modeling (LCOM) system represent the largest Air Force users. Since it is not the objective of this research effort to examine the impacts of sampling on every user of MDC data, the discussion which follows will be limited to these three systems.

Product Performance System. The major recipient of the MDC data is the Product Performance System (DO56), operated by the Air Force Logistics Command. This system receives and processes maintenance data from every unit operating under MDC documentation procedures, and it serves as a central distribution point for MDC data. As such, it becomes a key interface between the MDC system and most MDC data users. The DO56 system processes data which enables AFLC to perform a major portion of its logistics management functions. It consists of five separate subsystems described below (3):

D056A Edit and Error Analysis. This system serves as a central data distribution point for other system interfaces with the MDC system. The basic function of the DO56A system is to receive data, check it for format and compatibility, and either correct or remove records not passing the checks. This is accomplished by comparing the data with a master edit file containing all allowable data entries. The DO56A system also distributes data to the other four DO56 subsystems, other AFLC management information systems, and other users. The DO56A system does not prevent inaccurate data from being passed on to other systems. As long as the data format is correct, the codes used are compatible, and the data elements exist in the master edit file, the MDC data records are accepted (24).

<u>DO56B On Equipment Analysis</u>. The DO56B system receives all data concerning on-equipment maintenance. The basic function of the DO56B system is to provide structured reports for analysis of reliability trends, work unit code usage, inspection frequencies, corrosion problems, and cannibalization of parts. In general, these reports provide summary information of various maintenance activities at the aircraft or equipment system level by base, command, and weapon system. The DO56B system is primarily designed to support the AFLC system managers (24).

<u>DO56C Off Equipment Analysis</u>. The DO56C system receives all data concerning off equipment maintenance and provides structured reports concerning repair of components, repair capabilities, repair rates, and parts consumption. In general, these reports provide summary information of maintenance activities at the component and parts level, by base, command, and component. The DO56C system is primarily designed to support the AFLC item managers (24).

<u>DO56E Data to Contractors</u>. This system receives selected on and off equipment maintenance data from the DO56A system and operational data from the GO33B Aircraft Status Inventory and Utilization System. Data are then distributed to over 30 defense contractors and the Air Force Systems Command. The primary function of the DO56E system

is to provide feedback of information to the defense contractors where it is used to evaluate the field performance of current equipment. This information is also used to evaluate the need for design changes to improve current or future weapon system designs (24).

D056T Reliability, Availability, and Maintainability. The D056T system combines MDC data from the D056B On Equipment Analysis system and operations data from the G033B Aircraft Inventory Status and Reporting System, to provide summary reports of mean time between maintenance actions (MTBM), maintenance manhours per flying hour (MM/FH), and weapon system availability at the base and fleet levels. This information is used to assess the relative performance of weapon systems in terms of reliability, maintainability, and availability (24).

Visibility and Management of Operating and Support Costs (VAMOSC II). One of the major information systems using MDC data supplied by the Product Performance System is VAMOSC. VAMOSC is a management information system that gathers, tracks, and computes operating and support costs by weapon system (13:3). VAMOSC is essentially a cost collection system, rather than a cost accounting or cost estimating system. It is not a cost accounting system because no attempt is made to reconcile budget appropriations with actual expenditures. It is not an estimating system because it uses census data; thus, actual rather than estimated costs are collected (30:11). The information generated by the VAMOSC system is used as a basis for analyses of the following: force program balance; weapon systems comparisons; support resource planning; reliability and maintainability trade studies; logistics support alternatives; affordability studies; warranty/contractor support monitoring; and equipment maintenance management (30:6-7).

The VAMOSC system consists of three separate subsystems: the Weapon System Support Cost system (WSSC), the Communications-Electronics (C-E) cost system, and the Component Support Cost System (CSCS). Since this research will be primarily concerned with aircraft maintenance data reporting, only the WSSC and the CSCS systems will be discussed.

WSSC System. The WSSC system provides the user with operating and support cost information at the weapon system, or Mission-Design-Series (MDS) level, by base or at the fleet level. All costs associated with a weapon system are collected at a summary, or aggregate, level of detail. Costs that are directly accountable to a weapon system, such as fuel consumption, are charged directly to the system. Costs that are not directly accountable, such as installation security, are charged against the weapon system through various allocation formulas (13). The WSSC system uses direct maintenance manhour data provided by the MDC system, through DO56, as the basis for allocation of below depot maintenance costs by MDS (4:7). Manhour data are the only inputs supplied by the MDC system that are used by the WSSC system. All other cost data are supplied by other information systems.

CSCS System. The CSCS System provides operating and support cost information on the components of aircraft and equipment at the two and five digit work unit code (WUC) level, and/or the National Stock Number (NSN) level, by base and MDS (30:9). The CSCS system establishes a data base for use in portraying depot and base costs associated with an MDS. The aggregated data base is accumulated and retained at the MDS level for ten years and at the base level for five years (14:5).

The CSCS systems receives direct labor hour and actions taken data from the DO56 Product Performance System. The system sums all manhours reported through the MDC system by like WUC, MDS and base. Manhours are multiplied by the base labor costs and summed to determine the total labor costs of base maintenance. Total number of repair actions taken at the two and five digit work unit code levels are used as the basis to allocate material costs, supplied by the D002 Standard Base Supply System, to particular components by aircraft MDS (14:65-66).

Logistics Composite Modeling (LCOM) System. The LCOM system is the third major user of MDC data. Unlike most other users, MDC data needed to develop an LCOM simulation database are provided, on request, directly from the base at which the data are collected, rather than through the DO56 system. Both failure and manhour data are used in conjunction with the LCOM system, although the failure data are used to a much greater extent.

System Description. Air Force Regulation 25-5 provides a thorough general description of the LCOM system and it's uses:

> The LCOM system is a large scale computer simulation used to model manpower and other logistics requirements. It considers a random employment of different support resources and provides information to aid the user in deciding the best mix of resource levels to support a given requirement. LCOM capabilities range from simulating very small to very large weapon systems and other functions that lend themselves to simulation modeling. LCOM manpower studies may be developed for one or more locations or weapon systems. Because LCOM studies identify [both] peacetime and wartime requirements they provide a more defensible budget position and allow for effective utilization of available resources (10:1).

Use of MDC Failure Data. The failure data supplied by the MDC system are used to design networks in the LCOM simulation models. The networks describe mathematically the many complex maintenance activities for use in a computer simulation program. The failure data are used to determine both the frequencies with which failures occur and the frequency of the maintenance actions required to make repairs. These data are used to simulate random failures and the actions that would have to be taken to make repairs. In general, MDC data are used to model unscheduled maintenance requirements (7).

Use of MDC Manhour Data. To completely model the maintenance activities, the time required to perform a given task on a specific piece of equipment must be accurately determined. This type of information is collected by the MDC system; however, it is not sufficiently accurate for use in the LCOM model. In addition, since the LCOM model is used to determine manpower requirements for the organizations collecting the data, there could be a tendency to inflate the manhour data to justify a larger manpower requirement. As a result, maintenance task times are developed through other measurement techniques (8). The most widely used techniques are work measurement studies and operational audits. Work measurement studies involve the use of statistical sampling and are generally used to measure the time required for those tasks which occur frequently or that are easily observed. Operational audit techniques are used for those tasks which occur infrequently or are not easily observed. Operational audits consist of interviews with reliable and knowledgeable field personnel to ascertain the time required to complete specific tasks (7:C.1-C.9). MDC manhour data are used to validate LCOM simulation results. For example, maintenance manhour per flying hour data can be used to establish a baseline for validating the simulation results (7:5.53). The simulation results can be compared with the MH/FH data to insure that the LCOM results are logical and proportionally similar to the actual MDC manhour data.

Uses of Sampling in Maintenance Data Collection

Sampling has been used to collect aircraft maintenance data on at least two occasions. The Air Force studied the use of sampling to collect manhour data in 1977. In 1978, the U. S. Army implemented a sampling concept to collect unscheduled maintenance data at specific locations. The following sections of the literature review discuss these two uses of sampling to collect maintenance data.

MDC Modification Project. In June 1976, HQ USAF/LEY awarded a contract to Artronic Information Systems, Inc., to study the MDC system to determine whether manhour and equipment reliability data requirements could be satisfied through the use of statistical sampling techniques in place of a census (1:1). The study report, entitled "Project REALMS: Recommendations to Enhance the Air Logistics System," concluded that: the MDC system did not provide accurate information; the cost of data collection was too high; the data documentation was excessive; and the volume of data collected was so great that it was difficult to sort out the desired information. The study report recommended the application of statistical sampling techniques and trained observers to gather manhour data. The proposed benefits to be derived from sampling included: collection of more accurate manhour data; reduction of manhour documentation; reduction of keypunch requirements; and a reduction in the amount of MDC computer processing time (22:21). The Air Force questioned the technical aspects and cost effectiveness of sampling and felt there was need for a test to evaluate the impacts of sampling as recommended by the contractor. In July 1977, the Air Force issued a Program Management Directive (PMD) to the Air Force Logistics Management Center (AFLMC) tasking them to design and conduct a pilot test of a modified MDC system as described in the Project REALMS study report (1:1). The PMD required the development of sampling schemes which would provide estimates of total direct labor hours (DLH) expended with a relative statistical accuracy of not less than 6 percent for base level estimates and not less than 2 percent for fleet level estimates by weapon system. Analysis of this requirement indicated that it would require a larger number of observers than would be practical to conduct the pilot test. As a result, the PMD requirements were modified to require estimates of total direct labor hours expended in all activity at the base with 10 percent relative precision and 90 percent confidence. These estimates were to be further broken down by work center, MDS, and work unit code (5:1.1).

Two methods of estimating total direct labor hours were devised, one called "job sampling" and the other called "day sampling." Job sampling required the observation of a sample of maintenance tasks from start to finish. From the sample data, an average DLH per maintenance task was calculated and multiplied by the total number of maintenance tasks to determine total direct labor hours (5:1.1). Day sampling involved indirect work measurement by observing a workcenter supervisor for an entire eight hour shift, on several occasions, to note work crew dispatches managed by the supervisor. This observation provided an estimate of direct labor hours expended per shift. Total direct labor hours were then estimated by multiplying the average DLH expended per shift by the total number of shifts during the period of interest (5:1.1).

Both sampling plans were tested during a five day pilot demonstration at Reese AFB, Texas. The purpose of the pilot demonstration was to evaluate the administrative complexities involved in applying sampling techniques in an operational environment (5:1.2). Following completion of the pilot demonstration, the AFLMC concluded that although it was technically feasible to employ either of the sampling plans, administrative deficiencies far outweighed their technical feasibility. It was felt that the administrative deficiencies could severely impact the success of the sampling methods, resulting in the potential for greater inaccurate data collection than the current census. As a result of the pilot demonstration, the AFLMC recommended that further efforts to develop sampling plans for estimation of direct labor hours be discontinued (5:4.2). The PMD was subsequently rescinded by the Air Staff, and no further research was conducted into the use of sampling to collect maintenance data.

The MDC Modification Project was the subject of a 1979 Air Force Audit Agency report. The audit report faulted the study efforts on a number of points. The report charged that:

1. The scope, causes, and problems within the existing MDC system had not been sufficiently quantified in measurable terms to permit an accurate assessment of the effectiveness of sampling.

2. Prototype (sampling) design efforts proceeded without considering the MDC data user requirements and the impact of sampling on other MIS development projects.

3. The PMD objectives (more accurate data, reduced data collection costs, and reduced technician frustration) were not sufficiently quantified to permit measurement of the desired improvements and their impact on mission effectiveness resulting from the sampling methods.

4. The sampling methods would not provide sufficient failure data to support LCOM, manhour data to support the manhour per flying hour program, and maintenance data at the prescribed PMD levels of accuracy.

5. The sampling plans did not consider and would not meet the data requirements for the revised LCOM II system and the VAMOSC system (1:6-9).

The Air Staff response to these charges was that the MDC Modification Project was to proceed in several phases. The first phase of the project was a research effort to determine if the Air Force could develop usable sampling techniques to collect maintenance data. The basic position of the Air Staff was that the Audit Agency's comments were premature because the ability of the proposed sampling plans to provide data meeting the requirements of all users could not be known until the plans were fully developed, tested, and evaluated (1:10).

Army Sample Data Collection Programs. Until 1970, the U. S. Army collected maintenance and performance data on its equipment under The Army Equipment Records System (TAERS), which had been in effect since 1962. The TAERS reporting and data collection concepts closely paralleled those used in the Air Force MDC system. The TAERS system suffered from many of the same problems encountered in the MDC system. In 1968, a Department of the Army review of the TAERS system concluded:

1. The system was non selective and imposed an undue burden on the troops.

2. The volume of data gathered was unmanageable and its utilization at the field and national levels was questionable.

3. The cost of collecting and processing the data was prohibitive.

4. The validity of the data, because of the conditions under which it was collected, was suspect (19:1-2).

These findings closely resemble those found in a number of studies of the Air Force MDC system (22:44-50).

As a result of their findings, the Army adopted The Army Maintenance Management System (TAMMS) during the 1969-1970 time frame. The TAMMS eliminated 100 percent organizational and support maintenance reporting to the national level, except for aircraft. Provisions were made under the new concept to collect maintenance feedback data, when needed by equipment proponents, through sampling procedures (19:1-2). Under this sample data collection (SDC) method, data are only collected on systems when needed and fully justified to support a specific purpose (16). From an information systems standpoint, this requirement forces identification of user information needs before any data are collected. This concept virtually eliminates the collection of routine data which may or may not ever be used. Since the inception of the SDC concept, the Army reports that the SDC program has cost a total of $40.3 million, resulting in a cumulative tangible savings of $426 million--nearly a ten-fold return for each dollar spent administering the program and collecting the data (19:3).

Sampling Applied to Aviation. In 1978, the Army implemented sampling in the collection of aviation unscheduled maintenance activities. The Army definition of unscheduled maintenance, under the SDC concept, also includes time change and condition change maintenance actions (15:4). These actions in the Air Force system are considered scheduled. In general, the Army collects the same type of maintenance data through sampling that the Air Force collects by census.

To understand the Army's use of sampling in aviation maintenance, it is n essary to examine the sampling methodology used. The basic element of the sample is an Army aviation unit. From the population of Army aviation units associated with a specific type aircraft, a sample of units are selected to collect census data on all their assigned aircraft. Thus, some units collect maintenance data and others do not. The method of selecting those units which are included in the sample requires that a clarification of the use of sampling be made from a statistical viewpoint. Volume I of the Army Unscheduled Maintenance Sample Data Collection (UMSDC) data collection plan makes the following point:

> The SDC data base was not originally based on a probability sample. It is based on what is known as a purposive sample. The Department of the Army (DA) designated the units for which data were to be collected, based on administrative and logistic considerations. In a situation of this kind, the units designated may or may not be "representative" in the dictionary sense which defines the term as "typical of others of the same class." This definition is not sufficiently precise to enable one to determine objectively whether SDC is representative by a comparison of estimates from the purposive sample with numbers for the population of aircraft known from another source. The best that can be done is a subjective comparison. Subjectively, one can say that the SDC figures are in the [Table of Equipment] TOE ballpark (17:17).

The use of a purposive sample rather than a probability sample presents some difficulties if one desired to invoke the full power of inferential statistics. In order to use the statistical theories, the sample must be a probability sample. The term "probability sample" implies that each element of the population has a known, non-zero probability of being randomly selected for the sample. The Army recognizes that the data collected under their sampling concept in aviation maintenance is only directly applicable to the units and aircraft in the sample from a statistical point of view. Although no "proof" exists that the data collected is representative of the population, the Army treats the data as though it is representative mindful of the possibility that it may not be representative.

Comparison of Army UMSDC and Air Force MDC Systems

This section provides a side by side comparison between the MDC and UMSDC data collection systems. It compares the database design and format, the data elements, and the output products.

UMSDC Database Design. The basic design philosophy behind the UMSDC database was to provide feedback of field operational and maintenance characteristics of Army hardware for comparison with design predictions. The system was designed primarily to collect reliability, maintainability, and availability data, with maintenance management information as a by product (17:1). The MDC system, on the other hand, was designed primarily to provide maintenance management information, with reliability and maintainability data as a by-product (22:344).

The Army utilizes the Reliability, Availability, Maintainability and Logistics (RAMLOG) data collection system to capture all generated operational and maintenance data during the test and evaluation phase of equipment acquisition, employing the use of trained observers to collect the data. This concept would be costly and impractical beyond the test environment. Thus, the UMSDC system is used to continue the operational and maintenance data collection started during the test and evaluation phase for the duration of the equipment life cycle. The UMSDC data collection effort is conducted on a more limited scale than the RAM/LOG effort, using regular field personnel to collect the data. In addition, the RAM/LOG and UMSDC system data elements are based on the same data elements developed and used for the Logistics Support Analysis Record (LSAR). The LSAR is developed during weapon system design by the contractor designing the system. The result is a data base providing the same information relating to any phase of the equipment life cycle (15:1; 18:4-5). The Air Force has no such comparable system to collect the same information during both the test and operational phases of the equipment life cycle.

UMSDC Database Format. The data collected in the UMSDC system are stored in an automated data processing format compatible with the Statistical Analysis Software (SAS) System, a powerful statistical software package, which is resident on the computer used with the UMSDC system. This setup allows the easy use of the various statistical analysis routines without requiring extensive data manipulation (17:8). The Air Force MDC system has no statistical analysis software associated with it. Detailed statistical analysis of MDC data is not possible without extensive, usually manual, data manipulation. Although the MDC system provides census data and does not necessarily require this software for statistical inference purposes, there are many other statistical tests which could provide valuable analysis of the data. For example, statistical tests could be performed to check for significant changes in parameters over time or significant differences between bases and systems. Regression analysis can also be performed to measure linear relationsnips between data elements. The UMSDC database is designed with this analysis capability in mind. The MDC system was not designed for this purpose, although the MODAS system does provide a limited regression analysis capability to plot trend information.

UMSDC Database Elements. The data elements captured through the UMSDC program provide a basis for determining a significant number of RAM/LOG effectiveness measures, such as readiness, mission reliability, and support costs. UMSDC was designed to provide the most accurate possible determination of these measures. Table I provides a comprehensive overview of the effectiveness measures directly supported by the UMSDC data elements (17:21).

UMSDC provides information concerning operations, maintenance, and supply in one information system. Data elements are recorded showing the effects of each area on the other two. Specific data elements are recorded to show the effect of a malfunction on a mission; the source of the parts used to make the repair; and the reasons for mission delays. For example, such information could show that a

TABLE I

Weapon System Effectiveness Measures

Supported by UMSDC Data Elements

Reliability	Availability	Maintainability
MTBF	Inherent	MTTR
System Reliability	Achieved	Unscheduled MM/FH
Mission Reliability	Operational	Scheduled MM/FH
MTBR		MOS Utilization
MTBM		Direct MH/FH
MTB Red X Events		Indirect MH/FH

Operations	Logistics	Cost
Mission Abort Rate	POL Usage	Cost/FH
Usage Rate	Parts Usage	
	Ordnance Expended	
	Parts Delays	

Source: Army Sample Data Collection Plan, Aviation Applications Guide, Volume 1, Fig. 6.

partial equipment failure caused degraded mission performance; that a part had to be cannibalized because a spare was not available; or that a mission was delayed due to a repair that could not be made because the proper tools or test equipment were not available (15). This type of information is not available from the Air Force MDC system, although some of the information concerning mission delays is available through other data collection and reporting systems. In the UMSDC system, these data can easily be related to each other, while in the Air Force system they cannot.

TABLE II

Comparison of MDC and UMSDC Data

MDC System	UMSDC System
Job Control Number	Work Order Control Number
Workcenter Code	Unit Identification Code
Identification Number	Aircraft Serial Number
Standard Reporting Designator	Model No., Serial No., Location
Type Maintenance	All unscheduled[1]
Work Unit Code	Work Unit Code
Action Taken Code	Action Code
How Malfunction Code	Failure Code
When Discovered Code	When Discovered Code
Category of Labor	Direct Labor Only[2]
Manhours	Direct Manhours[2]
----[3]	Malfunction Effect Code
----	How Recognized Code
----	Transaction Code
----	Delay Code
----	Aircraft Status Code
----	Function Code
Base Code	Location Code
----[4]	Level of Repair
Employee Number/AFSC	Personnel Identification Code
Parts Replaced	Parts Consumed
----[5]	Narrative Description

[1]Includes TCTO and modifications.

[2]UMSDC only records direct "hands on" manhours expended during actual maintenance and does not apply to time consumed for parts/tool chasing.

[3]Two when discovered codes in the MDC system are related to mission aborts.

[4]Air Force has a separate data collection system for depot repair.

[5]MDC has provisions for narrative description on the AFTO Form 349; however, it is not entered into data system.

A side by side comparison of the Army UMSDC and the Air Force MDC coded data elements is provided in Table II. In general, the data collected in the MDC system are also collected in the UMSDC system. However, the UMSDC system provides the additional data elements described below (17:15-16):

a. Malfunction Effect Code. This code describes the actual effect a particular failure had on the ability to complete a scheduled mission. The MDC system provides limited mission effect data in conjunction with the When Discovered code.

b. How Recognized Code. This code relates how the fault or symptom of trouble was first recognized, such as cockpit display, noise, or vibration.

c. Transaction Code. This code indicates the supply source of the replacement part, such as from base supply or cannibalization.

d. Delay Code. This code indicates the reason for a mission delay as a result of a failure that could not be repaired. For example, non availability of parts, personnel, support equipment, or tools would be reported here as the reason for delay.

e. Aircraft Status Code. This code indicates the effect of a failure on the airworthiness of the aircraft. For example, the letter code X indicates the failure caused grounding of the aircraft.

f. Function Code. This code is used to compare the type of maintenance actions actually performed to the contractor estimates determined as part of the Logistics Support Analysis during the initial design. This data element captures the amount of calibration, adjustment or cleaning required to keep a component functioning properly.

UMSDC Operations Data. In addition to pure maintenance data, the UMSDC system also collects operational data similar to the data collected by the Air Force in the Aircraft Status and Inventory Utilization System. The collection of operations data was not originally a part of the UMSDC system. However, the Army felt that the full maintenance picture could not be understood unless the operation of the unit was also known (18:5). The operations data collected by the Army in the UMSDC program include the following: flight hour accumulations; flight/mission results; aircraft and weapon system status; cargo loads, passengers, and special equipment transported; fuels and ordnance consumed; type mission; and flight crew identification (15:7).

While similar operations data are also collected by the Air Force, the significant difference between MDC and UMSDC is that the Army collects all the data in one system, and the data are directly related to each other. This makes data analysis easier and produces more meaningful information. In the Air Force system, it is difficult to directly relate the impact of maintenance on operations and vice-versa beyond an aggregate measure.

Summary of Differences. The comparison between the Army and the Air Force data collection systems shows a basic similarity in the maintenance data collected by each service. The major differences noted were:

a. The Army collects only unscheduled maintenance and "hands on" man-hour data, while the Air Force collects all maintenance and manhour data.

b. the Army system is designed specifically to collect field R & M data, while the Air Force system provides this information as a by product.

c. the Army collects several additional useful data elements not found in the the Air Force MDC system.

d. the Army collects census data on all aircraft at specific locations, while the Air Force collects census data on all aircraft at all locations.

It should be noted that as a result of sampling, the Army is able to collect more detailed information than would be economically and administratively possible using a complete census.

Summary

The purpose of this literature review is to provide general background information regarding the structure of the MDC system, the uses of MDC data, and the application of sampling techniques to maintenance data collection. It also provides a detailed comparison between the MDC system and the Army Unscheduled Maintenance Sample Data Collection (UMSDC) program, so that the reader may have an appreciation of the detailed data that can be collected when sampling is used to reduce the data collection effort.

III. Methodology

Introduction

This chapter provides a description of the methodology used to answer the research questions posed in chapter I and presents an outline of the analysis to follow.

Background

This section presents the preliminary research that was conducted prior to the development of the sampling plans. It describes the parameters of interest and the precision requirements selected for the study.

MDC Data Base. The first step in this research effort was a review of pertinent literature concerning the MDC system. This provided a thorough understanding of the MDC system: the data collected; the structure of the data base; the data collection process; and the ultimate users of MDC data in other information systems. This review was essential in order to develop a sampling scheme to collect the same data currently collected by census, and to evaluate the impact of sampling on the users of MDC data. A summary of this review is contained in the literature review of chapter II.

Previous Sampling Studies. Sampling techniques have been used previously to collect maintenance data with varying degrees of success. Thus, the next step in the research process was an examination of the previous uses of sampling to determine where it had been successful and where it had failed. The intent was to capitalize on the successes and avoid the reasons for failure. Specifically, the U.S. Army Aviation Unscheduled Maintenance Sample Data Collection Program (UMSDC) and the Air Force Logistics Management Center (AFLMC) MDC Modification Project were investigated in depth.

Need for Census Data. Sampling techniques cannot and should not be considered an option in all cases. Although sampling could reduce the MDC data collection effort, some form of census data collection is unavoidable. For example, a permanent record of all operations, discrepancies, and maintenance performed on each aircraft is needed to monitor the condition of the aircraft. Whenever a failure or discrepancy occurs and maintenance is performed, the following information is recorded in permanent aircraft records (called aircraft "forms"):

1. description of the failure or problem
2. conditions present at the time the failure or problem was encountered
3. on equipment corrective action taken

Also recorded in the forms is the job control number assigned to each reported failure. This number is used by maintenance control to keep track of the maintenance status of each aircraft.

Currently, all failure and maintenance information for each discrepancy recorded in each aircraft's forms is also recorded on AF Form 349s, along with other details required by MDC. Under the proposed sampling scheme presented in this chapter, only data on the aircraft included in the sample would require recording and processing through MDC. However, the information described above would still need to be recorded in the forms on all aircraft. With an automated maintenance system concept, the aircraft forms are maintained and printed by the computer. The computer could be programmed to maintain a failure count by aircraft and work unit code, using the data in the aircraft forms. This could provide a method of collecting census failure data outside of the MDC system. Summary failure counts by work unit code could be compiled at base level and forwarded to AFLC by each base. Such a concept could provide the necessary failure data needed by AFLC without having to process and transmit all the data currently processed.

In addition to the information recorded in the aircraft forms, a count of no defect failures would also need to be reported by census. Total failures consist of type 1 (inherent), type 2 (induced), and type 6 (no defect) failures. A discrepancy documented in the aircraft forms as a type 1 failure may involve removal and replacement of a component. This "failed" component, when tested in the shop, may not indicate a failed condition. Thus, what was recorded as a type 1 failure is now reclassified as a type 6 failure. In order to insure an accurate failure count by type, these changes in type failure must be reported. Since the discrepancy had a job control number assigned to it initially, the computer could be instructed to change the type failure code for that job.

Lastly, those components on which lifetime data are being tracked by serial number will require that data be collected by census. This is necessary to provide complete data for reliability analysis.

Parameters of Interest. Basic to any sampling plan is the determination of what parameters are to be estimated. Two parameters of general interest derived from MDC data are the Mean Time Between Maintenance (MTBM) and the Maintenance Manhours per Flying Hour (MM/FH). MTBM provides an indication of system reliability, while MM/FH provides an indication of system maintainability. MTBM is determined by dividing total operating hours by the total failure count. Since total failure counts could be maintained by census, as described previously, there is no need to estimate MTBM by sampling. In this research, the proposed sampling plans are designed to estimate total unscheduled maintenance manhours from which unscheduled MM/FH can be estimated by dividing the estimated total unscheduled manhours by the actual population total flying hours. Manhours is chosen simply to illustrate the sample size required and should not be construed as the only data element to be collected by sampling. An implicit assumption is made that this sample size would result in the collection of other failure and maintenance details in sufficient quantity to satisfy the requirements of most MDC users.

<u>Sampling Precision</u>. Once the parameter of interest is identified, the degree of precision with which the parameter is to be estimated must be addressed. The required degree of precision for maintenance manhour estimates was not readily available. Since the current census data collection theoretically provides true manhour statistics with 100 percent statistical confidence (assuming the data are accurate), the issue of sampling precision has yet to be surfaced within the maintenance community.

A review of other sampling studies provided an indication of the sampling precision that might be acceptable to maintenance management. Of the two previous uses of sampling to collect maintenance data, only the AFLMC study specified any precision requirement. The Army does not use a random sampling scheme; therefore, no statistical precision is applicable. The Program Management Directive (PMD) guiding the AFLMC study stipulated that sampling should provide estimates of total direct labor hours expended in all maintenance activity at the base level with 10 percent relative precision and 90 percent confidence. In the absence of firm requirements, these precision requirements were adopted as a starting point for this research.

The proposed sampling plans will be designed to provide estimates of the base total monthly unscheduled maintenance manhours at the two digit work unit code (system) level with 10 percent relative precision and 90 percent confidence. If these precision guidelines result in the requirement for a very large sample size, the degree of precision that can be achieved with a smaller sample will be illustrated for possible consideration by management.

Sampling Plans

Unscheduled maintenance jobs are tracked either via the maintenance Job Control Number (JCN) assigned each time a failure is reported; or via the Serial Number (SN) of the aircraft on which the failure occurs. Sampling plans could be centered on either one of these methods. However, a sampling plan centered on the JCN was already evaluated during the AFLMC MDC Modification Project. It required a rather large sample size and was determined to be infeasible due to administrative complexities. Considering the AFLMC study results, this research effort will evaluate a sampling concept centered on the aircraft serial number.

Serial Number Sampling. A Serial Number (SN) sampling plan could be based on a simple random sample of aircraft by serial number. Each month an appropriate number of aircraft could be randomly identified by serial number to be included in the sample. Census data would then be collected on each aircraft in the sample during the month. Data collection would be identical to the data currently collected from the entire population by census.

Serial Number Sampling would provide failure counts, total unscheduled manhours, and other failure and maintenance details, by work unit code for each aircraft in the sample. Maintenance manhours could be summed by work unit code for each aircraft in the sample. Total sample manhours could be obtained by summing the individual aircraft values. Then the average unscheduled manhours per aircraft would be determined by dividing total unscheduled manhours for each work unit code by the total number of aircraft in the sample. An estimate of base total unscheduled manhours would result from multiplying the average unscheduled manhours per aircraft by the total number of aircraft assigned to the base. Unscheduled maintenance manhours per flying hour may then be estimated by dividing estimated total unscheduled manhours by the actual base total fleet operating hours.

Sample Design

This section presents information relating specifically to the design of the sampling plan. The discussion covers topics such as the relevant population, sampling frame, sampling unit, type sampling, and data collection.

Relevant Population. The population of interest using a serial number sampling plan is the entire fleet of a particular model of aircraft assigned to an individual base during a specified period of time. The relevant population arbitrarily selected for study in this research effort is the fleet of F-16A aircraft assigned to Hahn Air Base, Germany during the November 1984 through April 1985 time frame.

Sampling Frame. A sampling frame is a list of elements comprising the population from which the sample is actually drawn (20:151). The sampling frame for this study is the list of all F-16A aircraft assigned to Hahn AB during the period stated above. A listing of aircraft by serial number and base of assignment can be obtained through the G033B Aircraft Status Inventory and Utilization System.

Sampling Unit. Each aircraft in the sampling frame comprises a sampling unit. Each sampling unit consists of a number of subunits, the aircraft systems. As previously discussed, the parameter of interest for illustrating sample size requirements is unscheduled maintenance manhours. The total unscheduled manhours associated with each system on the aircraft is the parameter of interest for this study. To illustrate the procedures used to evaluate sample size, all unscheduled maintenance activity on one system, the F-16A Fire Control System (work unit code 74XXX), on each aircraft in the sampling frame will be considered the sampling unit.

Type Sampling. Random sampling in the serial number sampling plan is actually a special case of simple cluster sampling, with many clusters consisting of one aircraft each. In this situation, simple random sampling and simple cluster sampling are identical, since the only difference between the two is in the size of the cluster (20:175).

Cluster sampling involves dividing the population into many subgroups according to some criterion or ease of availability in data collection. Ideally these subgroups or clusters should display heterogeneity within groups and homogeneity between groups. A random sample of clusters is selected and each cluster is then typically studied in toto (20:172). Using the unscheduled maintenance activity for each individual aircraft as the sampling unit makes simple cluster sampling practical, as each aircraft represents a "natural cluster" of maintenance activity. As natural clusters, all maintenance activity on each aircraft is heterogeneous, as each aircraft contains a wide variety of systems, each requiring maintenance at different times. Likewise, all maintenance activity between clusters is homogeneous, as each aircraft of a given model will generally require approximately the same type and quantity of maintenance over time. The individual aircraft meet the requirements for acceptable clusters: heterogeneity within clusters and homogeneity between clusters.

Data Collection. To evaluate the application of sampling to the collection of unscheduled maintenance data, it is necessary to analyze the historical data to evaluate the characteristics of the parameter of interest. Data collection, in this section, refers to the collection of this historical data for analysis, rather than the collection of data by sampling.

MDC data used in the analysis will be obtained from the MODAS system Monthly Detailed Maintenance Data Search Reports. The reports will list, by aircraft serial number, all unscheduled "A" on equipment records and "B" off equipment records for the Fire Control System on the F-16A aircraft assigned to Hahn AB between November 1984 and April 1985. Manhours and total failure counts will be extracted from these reports for further analysis. Total operating hours and failure counts by month for the base fleet can be acquired from a MODAS Reliability Report. Summary base monthly manhour data can be obtained from a MODAS Summary Failure Data List.

Sample Size Determination

The primary factor that determines whether sampling by aircraft serial number is a practical and effective method of data collection is the size of the sample required to insure the precision requirements are met. The initial focus of the analysis will therefore be on demonstrating how the sample size can be determined.

Sample Size Calculation. Since simple cluster and simple random sampling are identical in this sampling design, it is possible to use the sample size formulas derived for simple random sampling. With precision stated in relative terms and sampling conducted without replacement, Equation (1) can be used to calculate the required sample size (32:83-86):

$$n = \frac{N\ [(Z)(C)]^2}{N\ d^2 + [(Z)(C)]^2} \qquad (1)$$

where

n = required sample size

N = population size

Z = normal Z score corresponding to the desired level of confidence

C = coefficient of variation

d = desired relative precision of the parameter to be estimated, stated in percent

The sample size is driven primarily by the degree of variability of the parameter of interest and the degree of statistical precision required. As previously discussed, the precision requirements of 10 percent relative precision with 90 percent statistical confidence as stated in the PMD guiding the AFLMC MDC Modification Project, will be applied to this study as well. Therefore, the focus of this section will be on examining the degree of variability in manhours per aircraft as the determinant of sample size.

<u>Coefficient</u> <u>of</u> <u>Variation</u>. The coefficient of variation, C, is defined as the ratio of the population standard deviation to the population mean. It can also be estimated by the ratio of the sample standard deviation to the sample mean (32:83-86). Fortunately, data concerning the entire population is available; therefore, it is simple to determine the actual population mean and standard deviation of

the parameter of interest. The coefficient of variation can then be accurately determined by simply taking the ratio of the two. All values can then be entered into equation (1) to determine the number of aircraft that would have been required in the sample, based on historical data, to estimate the total monthly base unscheduled maintenance manhours at the two digit WUC level with 10 percent relative precision and 90 percent confidence.

The determination of the sample size that would have been required, after the census data has already been collected, may or may not be of value in determining the sample size required to collect future data. If it can be demonstrated that historically the variability of the data is nearly constant over time, the sample size required to collect future data can be fixed accurately. However, if the variability is changing over time, the task is more difficult. In that case, the techniques in the following section may be used to fix the sample size.

Sample Size With Changing Variability. Three possible techniques that could be used to determine the required sample size if the variability of the data is known to be changing over time are proposed in this section. They are referred to as the "worst case," "average case," and "prediction" methods.

Using the worst case method, the sample size is fixed to satisfy the precision requirements for those months when the data variability is greatest. The resulting sample size would be larger than necessary during some months, but would be adequate to satisfy all precision requirements over time. In fact, the sample size might be quite large, since it would be based on the highest variability exhibited by any system on the aircraft in the past. However, using this technique the minimum statistical accuracy expected to be attained would be known with some degree of certainty. On the average, assuming no radical change in variability occurs, statistical accuracy would be above the minimum required, but in almost no case would it be lower.

Using the average case method, the sample size is fixed to satisfy the precision requirements based on the average variability of the parameter of interest over a period of time, say one year. The resulting sample size would be greater than necessary during some months when the actual variability is lower than the past average, but would be less than required when the actual variability is higher. Thus, attained statistical precision would fluctuate around the desired value.

If it is possible to predict the variability of the data over time with some degree of confidence, a more accurate sample size can be determined for each time period using the prediction method. Thus, if the variability was predicted to be low, a smaller sample would be needed, and vice-versa. Such a prediction might be possible using some type of a time-series forecasting technique, if there is a time dependency such as seasonality in the data. Some degree of seasonality would be expected in an analysis of past data. For example, seasonal patterns have been known to affect the performance of certain aircraft systems. Seasonal patterns caused by weather or operational commitments may impact how the aircraft are operated; how many flight hours are accumulated; and how and when maintenance can be performed or will be required. However, other factors which cannot be predicted, such as a change in operating and maintenance policies or concepts; technician experience levels; or source of spare parts may also contribute to the data variability. These non-seasonal and unpredictable effects could seriously impact the forecast accuracy of future variability. However, if a reliable forecasting technique were developed, the sample size requirement could be fixed more accurately than using either of the other two methods.

Data Analysis

This section presents the preliminary analysis to be conducted on the historical data base to determine how the sample size must be determined and what statistical analysis needs to be performed.

Level of Analysis. The level of detail at which to conduct a complete analysis will be determined after a preliminary analysis of the historical data. Data will initially be obtained at the two digit (system), three digit (sub-system), and five digit (component) work unit code (WUC) levels of detail for the Fire Control System. A random sample of ten aircraft will be selected for each of the six months of data to be analyzed. Total unscheduled maintenance manhours will be calculated for each of the ten aircraft at each level of detail. The sample mean, standard deviation, and coefficient of variation of unscheduled manhours per aircraft can then be calculated for each monthly sample at each WUC level. The coefficients of variation will then be compared for each month at each WUC level to determine which level has the least variability between aircraft. The same analysis will be conducted using the six month pooled sample data at each of the three levels. The level of detail exhibiting the least variability will be used in all further analysis, since the lower variability would require a smaller sample size.

Manhour Calculations. Once the level of detail for analysis has been selected, the entire population data at that level will be subjected to statistical analysis tests. Considering the volume of data to be analyzed, a simple Fortran computer program will be used to calculate the manhours from the start time, stop time, and crew size reported on each MDC data record. The program will sum on and off equipment manhours separately by aircraft serial number for each month. Total manhours per aircraft will then be computed manually by summing the on and off equipment manhours.

Those aircraft not appearing on the computer output will be assumed to have consumed no manhours during that month.

Data File. A database for the statistical analysis tests will be created from the manhours calculated as described above. This data file will contain the aircraft serial number, and it's associated manhours for each of the six months of data to be analyzed.

Statistical Tests

To determine the sample size needed to collect future data, the historical data must be analyzed to determine if the mean and variance of monthly manhours per aircraft is changing significantly over time. This analysis will also determine the method which should be used to fix the sample size. This section describes the methodology that will be used to analyze the data.

Three types of statistical analysis tests will be conducted on the database created for this purpose. Paired difference tests will be used to determine if the mean difference in manhours per aircraft between months is significantly different from zero. An analysis of variance test will be conducted to test all means simultaneously to determine if at least two of the means are significantly different. If possible, pairwise F-tests will also be performed to determine if the variance of manhours per aircraft is significantly different between months.

The statistical tests available to analyze the data are each based on a set of assumptions about the relationships between data elements and the distribution of the population to which the data belong. Parametric tests generally require that the data to be compared come from populations which are normally distributed, and that the samples are selected randomly and independently. For the paired difference test, the assumption of normality applies to the relative frequency distribution of the population of differences between two samples. The analysis of variance (ANOVA) test requires the additional assumption that the population variances are equal. This implies that an F-test on the population variances must be conducted to check this assumption. If the assumptions for the parametric tests cannot be met, then a non-parametric equivalent of the test will be used instead. Non-parametric tests do not require any assumptions about the shape or variance of the populations from which samples are drawn.

To determine which tests to perform, histograms of the raw data and differences will be plotted to determine if the assumptions of normality can be met. If the histograms appear to be normal the parametric test will be used, provided the other assumptions are met. If the histograms do not appear to be normal, the non-parametric test will be used.

Cost Considerations

Cost considerations normally have a major impact on the size and type of sample taken, as well as the data collection methods used. Cost is usually a budgetary constraint, limiting the sample size and dictating the logistics of data collection. However, in this application an attempt is being made to replace a census with a sampling concept. Sampling can only serve to reduce the cost of data collection, since less effort would be involved in collecting and processing the data.

A routine data collection infrastructure is already in place and operating at all Air Force bases. Certain fixed costs can be associated with the data collection effort in terms of hardware, facilities, and personnel, which are required regardless of whether data is collected by sampling or census. Certain variable costs can also be associated with the physical collection and processing of MDC data, such as the cost of the maintenance technician's time to enter data into a computer terminal, and the cost of computer processing for each MDC record.

The variable costs described above are somewhat artificial in nature and might actually be considered fixed, depending on the reader's organizational perspective. For example, the Air Force owns and operates it's own computers and would incur that operating cost in any case, regardless of the volume of data processed. From this perspective, computer costs are fixed. On the other hand, a charge may be levied against an organization for the amount of computer time actually used, and to that organization the same cost would be variable. However, in reality that unit is paying a portion of fixed costs allocated to users on the basis of computer time used. Considering the nature of military compensation, the cost of the maintenance technician's time will be incurred regardless of the volume of data collected. However, time not spent collecting and recording MDC data might better be applied to collecting improved reliability and maintainability data, or to performing other tasks. Nevertheless, the collection and processing of MDC data is not without cost, even if it is only the opportunity cost of using computer time and the maintenance technician for some other purpose. Therefore, the cost associated with collecting and processing MDC data will be considered variable, as described above, for the purpose of identifying potential cost savings that could be realized and applied to other uses as a result of sampling.

The costs of collecting and processing MDC data are incurred in three stages. First, the actual cost of collecting and entering data into the computer system is incurred at the base level. Included in this category is the cost of transmitting the MDC data from base level to AFLC Headquarters. The data are then processed through the D056 Product Performance System, where the second stage costs are incurred. Finally, the data from the D056 system are provided as input to other Logistics Command data systems and are sent to major commands, Air Force headquarters, and defense contractors, where the data are again processed in various ways.

Only the costs incurred in the first two stages will be considered for analysis in this study. All MDC data require roughly the same collection and processing effort during the first two stages; therefore, the variable cost per record can be estimated fairly easily. The third stage is more complicated to analyze, because all data is not used and processed in the same manner by all users. Many of these third stage users only process portions of MDC data records and perform various calculations and manipulations of the data to meet their individual needs. Cost of processing data can be significant at this level, depending on how the data are used. Identification of potential cost savings at this stage is beyond the scope of this study, but should not be discounted.

Base Level. At the base level, the variable cost of collecting data under the Automated Maintenance System or CAMS concept, is simply the labor cost of the technician's time to enter an MDC data record into a computer terminal. The cost of processing and transmitting the data is the charge incurred by the maintenance organization for these services.

To estimate data collection costs, the time required to enter one data record into the computer must be estimated. This time, multiplied by the average base direct labor rate, provides an estimate of the cost of physically collecting and entering the data. The average cost of data processing and transmission per record can be determined by dividing the charges for these services during a particular period by the total number of MDC records processed during that same period. Since the CAMS system has not been in operation long enough to provide this data, the cost data for the AMS system will be used as a representation of the costs that could be expected with CAMS. Not considered in this study are the annual costs associated with keypunch operations and maintenance under the manual MDC system, which were estimated in a 1982 study sponsored by the Logistics Management Center at approximately $9 million (6:6-7).

Logistics Command Level. The costs associated with the processing of MDC data at this level are incurred by the D056 Product Performance System, through which all MDC data are processed prior to delivery to other users. The cost of processing each record can be estimated by dividing the total charge for computer time during a specific period by the total number of records processed during the period.

Total Variable Costs. An approximate total variable cost of collecting and processing each MDC data record can be developed based on the costs identified in the first two stages described above. That cost can be used to place a rough monetary value on the use of sampling to collect MDC data. The total number of MDC records collected and processed annually can be determined with certainty from historical data. The total number of records multiplied by the average cost per record provides an estimate of the variable cost of collecting and processing data by census. The average number of MDC records per aircraft at the base level can be determined by dividing the total number of records by the average number of aircraft assigned during the year. The expected total number of MDC records that would be collected and processed by sampling could be approximated by multiplying the average number of MDC records per aircraft by the number of aircraft in the sample. The difference between the total number of records by census and the expected total by sampling, multiplied by the cost per record, represents the monetary value of sample data collection. This analysis would have to be conducted at each base to determine an overall savings if sampling were used throughout the Air Force.

Impact On Other Users

The first step in evaluating the use of sampling to collect unscheduled maintenance data is to determine the sample size that would be required to estimate manhours with a specified degree of statistical accuracy. If that analysis shows that sampling presents a significant cost savings and reduction in the data collection effort, the following additional analysis will be conducted to illustrate the impacts of sampling on users of MDC data. If sampling does not prove to be effective, the analysis will be limited to demonstrating the use of sample data in the Product Performance System, the VAMOSC program, and LCOM.

VAMOSC Program. The VAMOSC program Component Support Cost System (CSCS) collects and totals on and off equipment manhours at the two digit and five digit WUC level for the computation of component support costs. The CSCS system also sums total repair actions at the five digit WUC level for action taken codes A, F, and G for type 1 and type 2 failures. To determine how estimated manhours and total repair actions would impact the CSCS system, estimated figures can be substituted into the cost algorithms to demonstrate the use of sample data.

Logistics Composite Model (LCOM). In the LCOM model, the action taken codes are used to determine the frequency with which certain repair actions are required as a result of the operation of the aircraft and the failure of aircraft systems. To determine if the frequency of failure and maintenance details collected by sampling would produce the same result as that provided by a census, the proportion of total failures in the population resulting in specific LCOM action codes can be compared to the proportion of failures in the sample resulting in the same action code.

Summary

This chapter presents an outline of the analysis to follow in Chapter IV and places the research in perspective for the reader. The chapter provides the step by step research procedures to be used to answer the research questions posed in chapter I.

IV. Data Findings and Data Analysis

Introduction

This chapter presents a step by step description of the research that was actually conducted in this thesis study and presents an analysis of the data.

Preliminary Analysis

System Selection. The F-16A aircraft was chosen as the universe for analysis because it has been in the Air Force inventory for several years and the inventory is large. The aircraft located at Hahn Air Base were chosen for study because the average aircraft inventory at Hahn was fairly typical and appeared to be relatively stable over time compared to other F-16 bases. Additionally, Hahn is not routinely used as a deployment site for exercises and training, making identification of the population easier. The choice of Hahn AB was simply one of convenience to limit the amount of data manipulation required.

The Fire Control System, work unit code (WUC) 74XXX, was selected for analysis because it appeared in the MODAS Reliability and Maintainability Reports for April 1985 as the system with the highest failure rate and second highest manhour consumption of all systems on the F-16A. The choice of this WUC guaranteed availability of a large data base which could be quickly accessed through the MODAS system. The Inertial Navigation Subsystem, WUC 74DXX, and the

Inertial Navigation Unit, WUC 74DA0, were chosen for the subsystem and component level analysis for the same reasons.

Population Identification. Two methods of determining which aircraft comprised the population were actually used during the study. The first considered any aircraft which generated any on equipment MDC records during each month as part of the population. This method produced a constant list of 76 aircraft for each month. An alternate method considered any aircraft appearing on the Monthly Aerospace Vehicle Inventory by Station (AVIS) Report, produced by the GO33B system, as part of the population. This method produced a population which varied in size from 71 to 74 aircraft. The difference is attributed to the fact that MDC data is presented for an entire month while the AVIS report lists data as of the last day of the month.

Sample Data Analysis. A random sample of 10 aircraft was drawn for each month out of the population derived from MDC data. On and off equipment unscheduled manhours were calculated and summed for each of the aircraft at each each WUC level of detail. The mean, standard deviation and coefficient of variation for each month were calculated and compared between WUC levels of detail. The result is presented in table III. The 10 data points for each of the six months were then pooled at each level of detail and the mean, standard deviation, and coefficient of variation were again calculated. The result is presented in table IV. This prelim-

TABLE III

Comparison of Monthly Sample Data

	Nov	Dec	Jan	Feb	Mar	Apr
System 74XXX						
mean	8.54	14.80	3.29	7.76	17.17	18.88
standard deviation	7.74	11.97	5.59	9.28	19.41	14.97
coef. of variation	0.91	0.81	1.70	1.20	1.13	0.79
Sub System 74DXX						
mean	2.00	7.63	0.12	0.91	5.21	6.75
standard deviation	1.30	9.35	0.31	2.02	6.53	5.07
coef. of variation	0.65	1.22	2.58	2.22	1.25	0.75
Component 74DA0						
mean	0.40	1.90	0.00	0.60	6.68	4.18
standard deviation	0.84	4.54	0.00	1.89	8.65	5.21
coef. of variation	2.11	2.38	-	3.15	1.29	1.25

TABLE IV

Comparison of Pooled Sample Data

Level	Mean	Std. Dev	Coeff of Var
System	11.09	12.60	1.13
Sub-System	3.67	5.91	1.611
Component	2.29	5.02	2.180

inary analysis indicated the variability of total manhours per aircraft was greater at higher levels of detail. The relative variability, as measured by the coefficient of variation, was lowest at the system level; thus, WUC 74XXX was chosen for further analysis. The preliminary analysis also indicated the mean and variance of total manhours per aircraft might be changing significantly from month to month. This possibility has significant implications for sampling, as the variability of the data drives the sample size. Further detailed analysis was thus required.

Population Data Analysis

Manhour Data Calculations. To eliminate the possibility of sampling error, a decision was made to include the entire population data in any further analysis. A computer program, included in appendix A, was written to calculate and sum on and off equipment unscheduled manhours separately by aircraft serial number and month. A population data base was then manually constructed by totaling unscheduled manhours for each aircraft by month using the MDC data population of 76 aircraft. Aircraft which were not listed on the AVIS report were then excluded from the population to eliminate any bias because it was not possible to determine exactly when these aircraft entered or exited the population. Fifteen aircraft were eliminated in the process, leaving a total population of 61 aircraft for analysis. A computer data file, containing the aircraft serial numbers and their

TABLE V

Basic Manhour Statistics

Month	Mean	Standard Deviation	Coefficient of Variation	Smallest Value	Largest Value
Nov	14.914	20.112	1.34851	0.000	94.250
Dec	16.709	16.775	1.00399	0.000	96.000
Jan	3.906	7.883	2.01820	0.000	49.830
Feb	24.653	36.097	1.46418	0.000	229.170
Mar	30.960	25.937	0.83774	0.080	105.420
Apr	28.952	28.793	0.99347	0.000	141.420
Pooled	20.016	25.889	1.29341	0.000	229.170

associated total manhours for each month of the study, was created and is included in Appendix B.

Histograms of Data. Histograms of the total manhour data were plotted using a BMDP5D statistical analysis program. Three different types of histograms plotted were:

Monthly total manhours per aircraft (Appendix C).

Pooled monthly total manhours per aircraft (Appendix D).

Between month paired manhour differences (Appendix E).

Analysis of the data presented in the histograms indicated monthly unscheduled manhours per aircraft came from a distribution that appears exponential. The between month manhour differences appeared normally distributed.

Basic Statistics. The mean, standard deviation, coefficient of variation, and range for each month and for the pooled manhour data were calculated for the population and are presented in Table V. The coefficient of variation fluctuates between months to a larger degree than was noted for the random sample of 10 aircraft. Further analysis of the MDC data was thus necessary to determine if the change in the mean and variance was significant over time.

Statistical Tests

Several standard statistical analysis tests were conducted to determine if the change in mean and variance of unscheduled manhours per aircraft is significant. This section explains the tests, the reasons the tests were selected, and the test results.

Paired Difference T-test. A paired difference T-test was performed between each set of monthly data to test the null hypothesis

$$H_o: u_1 - u_2 = 0 \text{ (means are identical)}$$

against the alternate hypothesis

$$H_a: u_1 - u_2 \neq 0 \text{ (the means are different).}$$

The test is based on the assumptions that the relative frequency distribution of the differences is normally distributed and the differences are randomly selected from the population of differences. The individual monthly populations need not be normally distributed. Both assumptions were met.

TABLE VI

P Values of Paired Difference Test

	Dec	Jan	Feb	Mar	Apr
Nov	.4972	.0002	.0679	.0004	.0038
Dec	--	.0000	.1140	.0006	.0042
Jan	.0000	--	.0001	.0000	.0001
Feb	.1140	.0001	--	.1954	.4695
Mar	.0006	.0000	.1954	--	.6346

The test statistic, t, for the paired difference T-test is calculated by the following equation:

$$t = \frac{x_d}{s_d/n_d}$$

where

x_d = mean of the sample differences

s_d = standard deviation of the distribution of differences

n_d = number of paired difference data points

The rejection region for this test is

$$t < -t_{\alpha/2,n-1} \quad \text{or} \quad t > t_{\alpha/2,n-1}$$

where

$t_{\alpha/2,n-1}$ = critical value of the t statistic at the α level of significance with n_{d-1} degrees of freedom.

The test results in terms of P-values are presented in table VI. The P-value for a specific statistical test is defined as:

> ...the probability (assuming Ho is true) of observing a value of the test statistic that is at least as contradictory to the null hypothesis and is as supportive of the alternate hypothesis as the one computed from the sample data (27:295).

Thus, the lower the P-value, the stronger the conclusion that the means are significantly different. Analysis of the data presented in Table V shows that the means of the monthly data are significantly different in all but three of the fifteen cases analyzed. <u>This result presents rather strong evidence that the mean unscheduled manhours per aircraft is changing over time</u>.

<u>Kruskal-Wallis Test</u>. Analysis of the monthly unscheduled manhours per aircraft histograms indicated that manhours came from an exponential, rather than normal distribution. Thus, the parametric analysis of variance (ANOVA) test was not appropriate. The non-parametric equivalent of ANOVA, the Kruskal-Wallis H Test, which requires no assumptions about the shape of the population probability distribution, was used instead. The Kruskal-Wallis test is used to test the null hypothesis

H_o: All probability distributions are identical,

against the alternate hypothesis

H_a: At least two of the distributions differ in location.

The test statistic used for the Kruskal-Wallis is

$$H = [12/n(n+1)] \sum_{j=1}^{k} (R_j^2/n_j) - 3(n+1)$$

where

n_j = number of measurements in sample j

R_j = rank sum for sample j

n = total sample size = $n_1 + n_2 + \ldots + n_k$

k = number of populations to be compared

R_j, the rank sum, is computed by ranking the pooled data elements in the total sample in their relative order of magnitude.

The rejection region for the Kruskal-Wallis test is

$$H > \chi^2_{\alpha,k-1}$$

where

$\chi^2_{\alpha,k-1}$ = the value of the χ^2 distribution at the α level of significance with (k-1) degrees of freedom.

The Kruskal-Wallis test was conducted using a BMDP3S statistics program. The value of the test statistic, H, was computed as 78.88. At five degrees of freedom, the P-value was 0.0000. The result is a very strong conclusion that at least two of the monthly populations differ. This supports the conclusions of the paired difference t-tests, that the mean of monthly unscheduled manhours per aircraft is changing over time.

Analysis of the total unscheduled monthly manhours for the Fire Control System on the F-16As at Hahn AB reveals that unscheduled manhours for January are significantly lower than the other five months. This difference appears to be peculiar to Hahn AB. Analysis of data at the fleet level and at several other F-16A bases does not reflect the same trend. Total operating hours at Hahn AB are relatively constant over the six months studied. This raised a question of whether all January data had been collected and reported, or if it had been lost. Therefore, the Kruskal-Wallis test was repeated without the January data to see if the results would be affected in any way. The resulting H statistic was 23.88, with a P-value of 0.0001. The test still provides a strong conclusion that at least two of the distributions differ in location, and supports the evidence that the mean manhours per aircraft is changing over time.

Test for Equal Variance. The F-test to check for a significant difference in variance between two samples requires that both come from populations which are normally distributed. A review of the histograms indicates that this assumption cannot be met for the manhour data, thus the F-test could not be performed. Non-parametric tests for equal dispersion have been developed based on ranking the data and using the Wilcoxon rank statistic (26:83-113); however, none of these tests were contained in the statistical analysis programs available to the researcher. Time did not permit the manual performance of these tests; therefore, no absolute conclusions can be made concerning the variance of unscheduled manhours per aircraft over time as a result of this research.

Statistical Test Conclusions

The statistical tests were conducted to determine if the differences noted in the monthly mean and variance of unscheduled manhours were significant. The results of the statistical tests which could be performed produced strong evidence that the mean unscheduled manhours per aircraft changes significantly over time. Although no test was performed to confirm that the change in variance is also significant, a subjective review of the standard deviation and coefficient of variation for each month presented in Table IV shows a fairly wide range of values. In all probability the differences are significant; however, a statistical test is needed to confirm this assertion. Nonetheless, it is safe to conclude that the monthly unscheduled manhours per aircraft are not identically distributed.

Determining Sample Size

Three methods of determining sample size were presented in chapter III. The methods were proposed for use if the mean and variance of the parameter of interest were known to be changing over time.

Prediction Method. As discussed in Chapter III, a serial or seasonal time series forecasting model might be appropriate to predict the variability of manhours per aircraft such that the sample size is accurately fixed to meet the precision requirements. The development of a forecasting model in itself could be the subject of another research study. The actual use of such a technique in practice would require analysis of at least five years of monthly historical data to develop a reasonable degree of accuracy. The analysis would need to be conducted for each system on a given model aircraft at a given base, since the sample size would be based on the aircraft system with the highest variability of manhours per aircraft. This data is not readily available because the MODAS system only contains up to two years of monthly historical data, and because the manhour data is not compiled or tracked by aircraft serial number. Therefore, a computer program such as the one used in this study, would need to be run against at least five years of historical data to compute manhours by serial number.

In the absence of the required data and considering the level of effort that would be required to develop a forecasting technique, if one can be developed, the best approach that can be used is to determine the sample size by either the worst case or average case methods discussed in Chapter III.

Worst Case Method. Using this method, the sample size is based on the system with the highest variability in manhours per aircraft during a previous time period. Of the

TABLE VII

Variability and Sample Size

Month	Coefficient of Variation	Sample Size
Nov	1.34851	65
Dec	1.00399	58
Jan	2.01820	70
Feb	1.46418	66
Mar	0.83774	53
Apr	0.99347	58
Pooled	1.29341	64

six months of data analyzed for the Fire Control System, the highest coefficient of variation was experienced during the month of January, as indicated in Table VII. The sample size required each month for future data collection would be 70 aircraft based on an average population of 74. This figure was determined using equation (1):

$$n = \frac{N\ [(Z)(C)]^2}{Nd^2 + [ZC]^2} = \frac{(74)[(1.64)(2.01820)]^2}{(74)(.10)^2 + [(1.64)(2.0182)]^2}$$

$n = 69.31 = 70$ aircraft

where

N = population size

Z = 1.64 = Normal table Z value for 90% confidence

C = Coefficient of Variation = std dev/mean

d = .10 = 10% relative precision

TABLE VIII

Sample Size and Precision

Level of Confidence	Sample Size vs. Relative Accuracy 10%	15%	20%
90	64	54	45
85	61	50	40
80	58	46	36

Even if the January data were suspect, as previously discussed, a similar result is obtained using the next highest coefficient of variation which occurred in February. The resulting sample size would be 66 out of 74 aircraft. In both cases the result is almost a census.

Average Case Method. Using this method, the data for all six months are pooled and a coefficient of variation is calculated. The sample size required using this technique would be 64 out of 74 aircraft; less than that determined by the worst case method, but not significantly lower.

Sample Size and Precision. In addition to the variability of manhours, the level of confidence and the degree of statistical precision desired of the estimates have an impact on the sample size. Table VIII presents the sample size required for three levels of confidence and three degrees of relative precision based on the average case method. For each five percent of accuracy reduction, the sample size is reduced by 10 aircraft. For each five percent reduction in the level of confidence, the sample size is reduced from three to five aircraft depending on the relative precision. In general, the lower the relative precision and level of confidence needed in the parameter to be estimated, the lower the required sample size. Thus, if management can accept a lower degree of statistical precision than the 10 percent relative precision and 90 percent level of confidence used in this study, a smaller sample may be used.

Cost of MDC Data Collection

A methodology for estimating the approximate variable cost of collecting and processing MDC data was developed in Chapter III. The following cost function is based on using an automated maintenance system concept:

$$VC = (T) \times (L) + BPT + LP \qquad (2)$$

where

VC = total variable cost of collecting and processing one MDC record

T = average time to enter an MDC data record into a computer terminal

L = average maintenance technician labor rate per minute

BPT = base computer processing and transmission cost

LP = AFLC computer processing cost

Time to Enter Data. The average time required to enter MDC data into an automated system computer terminal was estimated from experience with the AMS at Dover AFB. The MAC

AD-A161 448 A FEASIBILITY STUDY OF THE COLLECTION OF UNSCHEDULED MAINTENANCE DATA USI..(U) AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH SCHOOL OF SYST.. R A HEINLEIN

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Management Engineering Team (MACMET) was in the process of developing a new LCOM simulation model for Dover and provided a time estimate for data entry. The distribution of time required to enter MDC data into the computer terminals at Dover averages one minute with a range of thirty seconds to four minutes. The actual time required in a given instance would depend on the availability of a computer terminal, machine response time, number of mistakes in data entry, and the proficiency of the technician.

Average Technician Labor Rate. The base maintenance direct labor rate varies substantially from one location to another. Manpower authorizations and grade structure of the maintenance organizations also vary between weapon systems due to differences in technical complexity, system reliability, and other factors. To address labor cost without considering these variances, the assumption was made that maintenance organizations are composed primarily of military personnel with an overall grade structure similar to the total Air Force grade structure. A weighted average technician labor rate for a maintenance organization, presented in Table IX, was developed from the current Hourly Composite Standard Rates for Military Personnel by Grade and the September 1984 USAF Total Active Duty Strength by Grade statistics ((10:270-272; 31:189). The rate calculated by this method was $12 per hour or 20 cents per minute. Since the

TABLE IX

Weighted Average Maintenance Technician Labor Cost

Grade	Total Force	Proportion of Total	AFR 177-101 Hourly Rate	Weighted Average
E-9	4,842	0.00995	24.64	.2450
E-8	9,963	0.01986	20.76	.4125
E-7	36,519	0.07508	17.86	1.3409
E-6	56,261	0.11566	15.23	1.7615
E-5	108,859	0.22380	12.74	2.8512
E-4	102,758	0.21125	10.94	2.3111
E-3	124,652	0.25626	9.33	2.3909
E-2	22,021	0.04527	8.49	0.3843
E-1	20,835	0.04283	7.25	0.3465
Total	486,410	1.000		$12.0079

average time required to enter one MDC data record into a computer terminal is one minute, the technician cost of this transaction is estimated at 20 cents.

Base Level Processing and Transmission. Cost of base level processing and transmission of MDC data were estimated from costs associated with the C-5A at Dover, Travis, and Altus AFBs. Cost of MDC data processing and transmission for the C-5 are tracked by HQ/MAC LGX. The most recent data available showed that the MAC Industrial Fund for the C-5 entered 689,000 transactions and was charged $12,485 by

TABLE X

DO56 Data Processing Costs

Month	Machine Hours	MDC Records Processed
Nov	164.5	2,228,997
Dec	201.1	1,826,667
Jan	129.5	1,710,095
Feb	195.0	1,739,172
Mar	218.75	2,386,405
Apr	109.5	1,929,925
Total	1018.35	11,821,261

Tinker Data Services for teleprocessing, or $0.018 per transaction (9). These costs are representative of those which could be expected for processing and transmitting base level data using an automated system concept.

AFLC Processing Costs. All MDC data is processed through the DO56 Product Performance System at AFLC Headquarters. The DO56 system is composed of five different subsystems, each of which is assessed a charge for computer machine time. Although every MDC record is not processed through all five systems, it was not possible to determine how many records were processed by each individual system. A total MDC record count was readily available for the DO56A system, which does process every record. Average per record cost of DO56 data processing was estimated by summing all DO56 machine time over a six month period, multiplying by the hourly rate, and dividing the result by the total number of records processed through DO56A during the same period. Machine time was provided by AFLC/AD and total record counts were provided by AFLC/MME-2 and are shown in table X (23). Machine hours are charged at a rate of $144 per hour; thus, the cost of processing each MDC record by the DO56 system using this method was calculated at $0.0124 per record.

Total Variable Cost. The per record variable cost of collecting and processing MDC records estimated using equation (2) is:

$$\begin{aligned} VC &= [(T) \times (L)] + BPT + LP \\ &= [(1 \text{ min.}) \times (\$.20/\text{min.})] + \$0.018 + \$0.0124 \\ &= \$0.2304 \text{ per record} \end{aligned}$$

Using this function, the total variable cost of collecting and processing approximately 23 million MDC records produced annually is estimated at $5.3 million per year.

Potential Cost Savings

Based on the sample size requirements using the worst case and average case methods, the cost savings that would result from sampling are rather small. The total number of MDC records collected at Hahn AB during the last year was 43,494 of which 29,065 records (67%) were unscheduled type "A" and "H" records, for an average of 393 unscheduled records per aircraft. Savings at Hahn, using the worst case method, would be 4 aircraft, 1568 records, and $361. Using the average case method, the savings would be 10 aircraft, 3930 records, and $905.

It would be impossible to extrapolate the potential cost reduction from sampling described above to estimate potential savings throughout the Air Force. The analysis was conducted on only one system at one base, and merely illustrates a methodology that can be used to make such an estimate. Other systems may exhibit even greater variability in manhours per aircraft, requiring an even larger sample size, with the extreme being a complete census. The sample size could also be different for different aircraft, different bases and different population sizes; thus, cost savings would be different at each base.

Impact on Other Data Systems.

The sample size required to collect MDC data based on the precision requirements was quite large and cost savings as a result of sample data collection would probably be quite small. Since implementation of a sampling concept to collect MDC data would be doubtful, a detailed analysis of actual data provided by the serial number sampling plan was not conducted. However, based on the methodology of the sampling scheme, the following observations can be made.

Logistics Composite Modeling. The inputs for the LCOM model derived from the MDC data are the relative frequency distributions of failures, actions taken, type failure, type maintenance, and the like. Absolute total figures are not needed. Exactly the same type of census MDC data would be collected using the serial number sampling approach, but only on a sample of aircraft. Therefore, the same type of information would be available for LCOM.

Manhour inputs for LCOM are developed from sources other than MDC data. The use of MDC data for LCOM would therefore not be affected by the fact that sampling is based on manhours per aircraft. The only impact that serial number sampling would have on developing an LCOM simulation data base is that it might be necessary to use historical data collected over a longer period of time than is needed with a census.

VAMOSC. The Visibility and Management of Operating and Support Costs is essentially a cost collection system rather than an accounting or cost estimating system. Sample data would change the VAMOSC program to a cost estimating system. The impact on the WSSC and CSCS systems of VAMOSC will be discussed in the following two sections.

The Weapon System Support Cost System (WSSC). The WSSC system of VAMOSC uses MDC manhour data to allocate below depot maintenance costs at the base level by aircraft mission-design-series (MDS). At bases where several different MDS aircraft are collocated, the cost of using maintenance resources are allocated to each MDS by the proportion of manhours used. With serial number sampling this allocation would be based on estimated total manhours rather than actual total manhours.

<u>Component Support Cost System (CSCS)</u>. The CSCS system of VAMOSC uses MDC manhour data and actions taken data. Manhours are summed by like work unit code (WUC), base and MDS and multiplied by the base direct labor rate to calculate the base labor costs by MDS. Using serial number sampling the base labor costs would be estimated, with the same degree of statistical precision associated with the manhour estimate. Actions taken codes are summed at the two digit and five digit WUC levels to calculate the total number of repair actions at various levels of detail. This figure is used to calculate the base direct material costs by WUC and MDS. Total repair actions could be estimated from the sample data by multiplying the average number of repair actions per aircraft by the total number of aircraft at the base. This estimate would have a known degree of statistical precision, although it would not necessarily be the same as the precision associated with the manhour estimate.

<u>Product Performance System (DO56)</u>. The DO56 system processes all MDC data records collected at base and depot levels. With the use of serial number sampling, the data collection and processing methodology is virtually unchanged; thus, the impact on the DO56 system would be minimal. The volume of data processed would be reduced, which

could improve the timeliness of the data system to users. Some additional programming would be required to calculate the statistics associated with the sample data and the population summary estimates.

Conclusion

There were a number of major findings as a result of the analysis of the MDC manhour data for the F-16 Fire Control System at Hahn AB. Monthly unscheduled manhours per aircraft were found to have large variability, requiring a rather large sample size to estimate the total unscheduled maintenance manhours at the two digit WUC (system) level with 10 percent relative precision and 90 percent confidence. The total variable cost of collecting and processing MDC data at base level and at AFLC headquarters was found to be significant. However, because of the large sample size requirement based on the variability of historical data, it appears that the potential cost savings as a result of sampling by aircraft serial number are small.

V. Summary, Results, Conclusions, and Recommendations

Overview

This chapter summarizes the research effort, presents results in terms of the research questions, draws conclusions, and offers recommendations for further research.

Summary

This study explored the feasibility of using statistical sampling techniques to collect the Air Force maintenance data currently collected by census in the MDC system. Sampling is explored determine if the volume of MDC data collected could be reduced and still provide management with the type of data currently available from the MDC system. If sampling is sufficient to provide management with this data, the effort and cost of collecting and processing MDC data could be reduced. The study does not address the question of whether management truly needs or uses the type of data currently provided by the MDC system. The assumption was made that the data are needed and used, although the assertion has been made time and again that they are not.

The focus of the study is twofold. First a practical sampling methodology is identified and the resulting sample size that would be required to collect data with a specified degree of statistical precision is illustrated. Then the variable cost of MDC data collection and processing is identified. Based on the required sample size and the cost of data collection the potential cost and effort savings resulting from sampling are evaluated.

The sampling methodology developed is based on a simple random sample of aircraft, by serial number, with census data collected on all aircraft in the sample. To estimate the required sample size, the sampling plan is designed to estimate the base level monthly total unscheduled maintenance manhours at the two digit work unit code (system) level. The methodology used to estimate the variable cost of collecting and processing MDC data records is limited to base and Air Force Logistics Command (AFLC) levels. Base level costs considered are the opportunity cost of a maintenance technician's time to enter one MDC record into an automated system terminal and the cost of computer processing and transmission of data to AFLC. AFLC costs considered are the machine time charges assessed against the D056 Product Performance System.

Results

The following results are presented in relation to the research questions that guided the study.

Research Question 1. What sampling plan(s) can be best be applied to the collection of aircraft failure and maintenance manhour data to provide the same type of information that is currently provided to users of the MDC data?

Two possible sampling plans which could be used to collect MDC data are identified: sampling by job control number and sampling by aircraft serial number. Job control number sampling involves collecting MDC data on a random sample of maintenance jobs and then estimating total unscheduled maintenance manhours from the mean manhours per maintenance job. This sampling methodology was previously evaluated by the Air Force Logistics Management Center and found to be administratively infeasible; therefore, it was not studied further. Serial number sampling involves collecting census MDC data on a random sample of individual aircraft and then estimating total unscheduled manhours from the mean manhours per aircraft. Collection of census data on a sample of aircraft closely resembles the current MDC system and could thus be implemented without any major changes in the existing data collection infrastructure. Sampling by aircraft serial number is therefore considered to be the sampling plan which could best provide the same type of information that is currently available to users of the MDC data.

Research Question 2. What degree of statistical precision can be obtained by sampling and how large must the sample size be?

Based on the average variability of manhours per aircraft of one system on the F-16A aircraft at Hahn AB, 86 percent of the base aircraft population would need to be sampled to estimate base monthly total unscheduled maintenance manhours with 10 percent relative precision and 90 percent confidence. If the relative precision requirement is reduced to 20 percent, only 61 percent of the aircraft population would need to be sampled. If the confidence level is also reduced to 80 percent, then only 49 percent of the aircraft population would need to be sampled.

Research Question 3. How can the sample data be used and related to the entire population to obtain information such as Maintenance Manhours per Flying Hour (MM/FH) and Mean Time Between Maintenance (MTBM)?

MDC data provided by serial number sampling produces little change over the current use of census MDC data. Sample MM/FH and MTBM can be calculated in exactly the same manner as currently determined for the population, by simply using the manhours, failure counts and operating hours of those aircraft in the monthly sample.

Relating sample data to the population requires a slightly different approach. Population MH/FH is estimated by simply multiplying the sample mean monthly manhours per aircraft by the number of aircraft in the base population and dividing the result by the total base population operating hours. Likewise, population MTBM can be estimated by dividing the total population operating hours by the mean failures per aircraft multiplied by the total number of aircraft in the base population. In this study, failure counts were assumed to be collected by census, since all failures need to be reported before maintenance can be performed. However, MTBM could conceivably be estimated as described.

It should be noted that population manhours cannot be estimated by multiplying the sample MM/FH by the total operating hours, nor can failure counts be estimated by dividing total operating hours by the sample MTBM because manhours, failure counts, and operating hours are all random variables. Estimation of the population manhours and failure counts in this manner would be a ratio estimate. This requires that the exact mathematical relationships between manhours and operating hours and failures and operating hours are known. The exact mathematical relationships are not known.

<u>Research Question 4</u>. Will sampling provide significant cost savings over the current census data collection methods?

The total per record variable cost of collecting and processing MDC data using an automated system approach at the base and AFLC Product Performance System levels is estimated at $0.23. Thus, the total variable cost of collecting and processing approximately 23 million MDC records annually is estimated at $5.3 million.

The sample size required to estimate base level monthly unscheduled maintenance manhours at the two digit work unit code level, with 10 percent relative precision and 90 percent confidence would be quite large; in many cases approaching a census. Annual cost savings at Hahn AB, using the sample size of 70 out of 74 aircraft for the worst case variability, and 64 out of 74 aircraft for the average variability, would amount to approximately $300 and $900 respectively. Based on this limited study it would be impossible to project a total cost savings for the Air Force resulting from sampling; however, the total savings would probably be small. If a forecasting method can be developed to accurately predict the manhour variability in advance, it might be possible to fix the sample size more accurately to meet the minimum precision requirements. This might reduce the sample size requirement and could result in a larger cost savings through sampling.

<u>Research Question 5</u>. What is the impact of the use of sample data on LCOM, VAMOSC, and the Product Performance System?

This research indicated that the sample size required to collect MDC data was so large, because of the variability in manhours, that implementation of a sampling concept would be doubtful. Therefore, a detailed analysis of the MDC data that would be provided by sampling was not conducted. Thus, research question five cannot be answered definitively; however, the following observations can be made.

<u>LCOM</u>. The design of the aircraft serial number sampling methodology should be sufficient to satisfy the requirements for LCOM. The only impact that serial number

sampling would have on developing an LCOM simulation data base is that instead of using only the latest six months to one year of base level MDC data, it might be necessary to use data collected over a longer period of time.

VAMOSC. The Visibility and Management of Operating and Support Cost Program is essentially a cost collection system rather than an accounting or cost estimating system. The use of sample data would effectively change the VAMOSC program from a cost collection to a cost estimating system, with estimates having a known degree of statistical precision.

Product Performance System (DO56). The DO56 system processes all MDC data collected at base and depot levels. With the proposed method of sampling by aircraft serial number, the actual data collected would remain unchanged; only the volume would be reduced. However, some additional programming would be required to calculate the statistical precision of the sample data and to estimate the population summary figures now developed from the census data.

Research Question 6. How can sampling be practically administered and controlled in the field?

The implementation of the CAMS system offers some unique opportunities for the use of automated routines to insure that sample data are collected on the right aircraft, at the right time, and in the correct format. Theoretically, computer routines could be used to direct the entire sample data collection effort. As with any data system, controlling the data collection to prevent bias presents a problem. Undetected bias could have a greater impact on the estimates made from sample data than it would on the actual results using census data; however, because of the reduced volume of data collected and processed more effort can be directed toward insuring that only accurate data is collected.

Conclusions

The objective of this research effort was to determine whether statistical sampling is a practical and feasible method of reducing the volume and cost of MDC data collection without losing any valuable information. The objective has been met with mixed results.

The conclusion reached as a result of this study is that sampling by aircraft serial number is a practical method of collecting MDC data. The method is simple; requires little change in the way data are collected, processed, and used; and would be relatively easy to implement. However, in the absence of a forecasting technique to predict the variability of monthly unscheduled maintenance manhours per aircraft, the use of sampling appears to be infeasible. The sample size required to estimate base total monthly unscheduled manhours with an acceptable degree of statistical precision, based on the greatest or average variability of the historical data, is nearly the same as a census.

Statistical sampling by aircraft serial number, as presented in this study, does not appear to be a viable alternative to a census given the current data structure of the MDC system and the assumption that manhour data is needed and can only be collected through the MDC system. Any cost savings resulting from statistical sampling are insignificant, unless a forecasting technique to predict future variability can be used to lower the sample size requirement.

Recommendations For Further Research

Based on the research results, no further research is recommended on the use of statistical sampling to collect MDC data, as the system is currently structured. However, two additional areas do offer some potential for further study and analysis.

Sampling Concept. The U. S. Army Unscheduled Maintenance Sample Data Collection (UMSDC) System uses a different sampling concept than proposed in this study. Selection of the bases for data collection is not random, but made on the basis of other considerations. The Army sampling concept is not statistical sampling and thus the data collected may or may not be representative of all aircraft.

This research study avoided the use of non-statistical sampling concepts, such as that used by the Army, for several reasons:

1. Aircraft of the same model are located in many different environments, and it is believed that failure patterns and maintenance requirements differ significantly by location.

2. Maintenance organizations, policies, and philosophies are believed to be different between bases and between commands; thus, the quality and type of maintenance and the resulting performance of the aircraft may differ significantly by location.

3. Aircraft of the same model may be used for different missions at different locations. Mission profiles and use of the aircraft may thus be different, and it is believed that failure patterns and maintenance requirements would differ by location.

As a follow on to this study, interested researchers could investigate the failure patterns and maintenance requirements of the same model aircraft at different locations to determine if in fact there are statistically significant differences between locations, commands, and mission profiles. If no differences are found, then a sampling concept similar to that used by the Army might be considered for use by the Air Force.

Use of MDC Data. Manhours per flying hour (MM/FH) is one of the main parameters of interest derived from MDC data. However, MM/FH could not be estimated directly by sampling because a known direct relationship between maintenance manhours and flying hours does not exist. For example, total unscheduled manhours for the population cannot be estimated by multiplying the sample MM/FH by the total number of hours flown, because manhours is a function of several parameters, only one of which is flying hours.

For this reason unscheduled manhours per aircraft was chosen the parameter on which to base estimates of the total population manhours. When manhours per aircraft were plotted on a histogram, the resulting distribution appeared to be exponential in nature. Considering the lack of an apparent direct relationship between manhours and flying hours, and an apparent recognizable distribution of manhours per aircraft, research in the following areas is recommended:

1. Investigate the relationship between manhours and flying hours. The use of the MH/FH statistic implies that a direct relationship between these parameters exists and that future manhours consumed can be predicted if one knows the past MH/FH and the expected number of hours to be flown in the future. It also implies that different aircraft models can be compared on the basis of MH/FH. If there is no direct relationship between manhours and flying hours, the choice of this statistic for analysis and comparison may be inappropriate and misleading.

2. Further investigate the distribution of unscheduled manhours per aircraft. This research study considered only one system, on one aircraft model, at one base. Further

research and more data analysis is required to determine if other systems and other aircraft exhibit the same apparent distribution of manhours per aircraft. If manhours per aircraft follow a known distribution, then perhaps it would be a more appropriate statistic than manhours per flying hour.

APPENDIX A: Manhour Calculation Program

```
      PROGRAM MANHRS
      INTEGER CREW(500), RECNUM, SERNUM(500),YEAR ,J
      REAL END,START,TMNHRS,MNHRS(500),TOTAL
      INTEGER STOP1(500),STOP2(500),START1(500),START2(500)
      CHARACTER MONTH*3, WUC*5,TYPE*9
C     TOTAL = TOTAL MANHOURS
C     TMNHRS = TOTAL MANHOURS FOR EACH AIRCRAFT
C     CREW = CREW SIZE
C     RECNUM = NUMBER OF RECORDS
C     SERNUM = LAST FOUR OF AIRCRAFT SERIAL NUMBER
C     END = STOPTIME IN MINUTES
C     START = START TIME IN MINUTES
C     MNHRS = MANHOURS FOR ONE MDC RECORD
C     STOP1 = STOP TIME HOURS
C     STOP2 = STOP TIME MINUTES
C     START1 = START TIME HOURS
C     START2 = START TIME MINUTES
C     MONTH = MONTH IN WHICH DATA COLLECTED
C     WUC = WORK UNIT CODE
C     TYPE = TYPE MAINTENANCE
      MONTH='AAA'
      WUC='XXXXX'
      TYPE='SSSSSSSSS'
      YEAR=9999
      TOTAL=0.0
      TMNHRS=0.0
      J=0
      RECNUM=0
      END=0.
      START=0.
      DO 100 I=1,500
         START1(I)=0
         START2(I)=0
         STOP1(I)=0
         STOP2(I)=0
         CREW(I)=0
         MNHRS(I)=0.0
         SERNUM(I)=0
100   CONTINUE
      OPEN(9,FILE='A85XOF',FORM='FORMATTED')
      OPEN(10,FILE='DATA',FORM='FORMATTED')
      REWIND 9
      READ(9,15)RECNUM,MONTH,YEAR,WUC,TYPE
      READ(9,80,END=500)(SERNUM(I),START1(I),START2(I)
     C STOP1(I), STOP2(I),CREW(I), I=1,RECNUM)
500   WRITE(10,14)
      WRITE(10,5)MONTH,YEAR,WUC,TYPE
      WRITE(10,10)
```

```
      WRITE(10,20)
      DO 600 I=1,RECNUM
           IF(STOP1(I).LT.START1(I))THEN
             STOP1(I)=STOP1(I) + 24.0
           END IF
         END=STOP1(I)*60.+STOP2(I)
         START=START1(I)*60.+ START2(I)
         MNHRS(I)=((END-START)/60.)*CREW(I)
           IF(STOP1(I).GT.24.0) THEN
             STOP1(I)=STOP1(I)-24.0
           END IF
         WRITE(10,30)SERNUM(I),START1(I),START2(I),STOP1(I),
     C   STOP2(I),CREW(I),MNHRS(I)
         J=J+1
           IF(J .EQ. 40)THEN
              WRITE(10,14)
              WRITE(10,5)MONTH,YEAR,WUC,TYPE
              WRITE(10,10)
              WRITE(10,20)
              J=0
           END IF
600   CONTINUE
      J=0
      WRITE(10,14)
      WRITE(10,5)MONTH,YEAR,WUC,TYPE
      WRITE(10,40)
      WRITE(10,50)
      DO 700  I=1,RECNUM
         TMNHRS=TMNHRS + MNHRS(I)
         IF(SERNUM(I).EQ.SERNUM(I+1))GO TO 700
            WRITE(10,60)SERNUM(I),TMNHRS
            TOTAL=TOTAL + TMNHRS
            J=J+1
               IF(J .EQ. 40)THEN
                  WRITE(10,14)
                  WRITE(10,5)MONTH,YEAR,WUC,TYPE
                  WRITE(10,40)
                  WRITE(10,50)
                  J=0
               END IF
         TMNHRS=0.0
700   CONTINUE
      WRITE(10,90) TOTAL
5     FORMAT(' ',A3,2X,I4,3X,A5,2X,A9)
10    FORMAT('0',15X,'MANHOURS BY RECORD')
15    FORMAT(I3,1X,A3,1X,I4,1X,A5,1X,A9)
14    FORMAT('1','MONTH  YEAR  WUC   TYPE MAINTENANCE')
20    FORMAT('0','SERIAL NUM STARTTIME STOPTIME CREW  MAN
     C HOURS')
30    FORMAT(' ',3X,I4,5X,I2,1X,I2,5X,I2,1X, I2,5X,I1,5X ,
     C F8.2)
40    FORMAT('0',5X,'MANHOURS BY SERIAL NUMBER')
```

```
50   FORMAT('0','SERIAL NUM    TOTAL HOURS')
60   FORMAT(' ',3X,I4,6X,F8.2)
80   FORMAT(I4,1X,I2,1X,I2,1X,I2,1X,I2,1X,I1)
90   FORMAT('0','GRAND TOTAL',2X,F8.2)
     STOP
     END
```

Appendix B: Manhour Data File

Serial Number	Nov	Dec	Jan	Feb	Mar	Apr
		Unscheduled Manhours			WUC 74XXX	
0543	39.83	33.83	0.00	6.00	40.00	24.75
0544	18.00	0.00	0.00	14.83	21.92	42.08
0545	23.75	5.83	16.00	7.00	68.17	36.33
0546	0.00	14.00	0.00	16.00	25.50	40.83
0555	16.00	0.00	0.00	0.00	11.00	35.75
0556	1.00	0.00	12.00	8.50	92.35	28.00
0559	24.00	12.00	0.17	24.00	32.00	48.33
0561	0.00	7.50	0.00	28.00	10.83	35.00
0574	16.00	37.83	0.00	0.00	26.83	97.67
0576	32.83	13.50	0.00	0.00	19.00	24.25
0585	0.00	8.00	0.00	0.00	11.50	37.00
0587	2.25	29.00	8.00	61.75	94.00	37.25
0588	6.17	26.50	5.50	22.00	28.17	88.83
0589	22.00	7.00	49.83	24.12	12.08	8.33
0590	0.00	0.00	3.00	17.25	9.00	0.00
0592	76.00	96.00	0.00	13.50	74.00	44.25
0601	6.50	30.00	0.00	102.50	2.00	54.33
0602	94.25	18.00	0.00	22.00	5.00	0.00
0604	13.67	6.00	0.00	4.00	72.50	141.42
0605	32.67	31.00	12.50	24.00	39.00	41.67
0606	0.00	0.00	0.00	28.00	105.50	0.00
0607	2.00	15.67	0.00	78.00	16.92	12.00
0608	27.00	0.00	3.00	22.00	28.00	6.00
0612	0.00	21.83	4.00	1.33	12.50	36.67
0613	0.17	2.50	0.25	3.00	67.75	27.92
0614	63.34	11.00	14.83	0.00	28.33	25.25
0615	19.50	29.00	0.00	3.00	17.00	0.00
0618	6.00	10.33	0.00	0.00	27.75	24.42
0620	19.00	12.00	8.17	41.00	28.50	0.00
0622	0.00	21.83	3.00	0.00	8.00	6.00
0665	18.00	10.50	8.00	47.83	48.00	32.75
0666	7.34	0.00	0.00	28.17	0.25	0.00
0669	15.00	33.50	0.00	29.50	18.17	0.00
0671	13.00	6.50	9.00	38.00	42.42	16.92
0672	0.33	0.00	5.58	3.67	49.75	77.08
0673	0.00	12.00	18.67	0.00	52.50	56.75
0674	7.00	14.00	0.00	12.00	54.33	53.00
0680	14.50	34.00	0.00	229.17	100.25	57.50
0681	2.00	4.00	0.00	49.83	8.58	77.50
0694	10.83	0.00	0.00	14.00	44.17	0.00
0695	0.00	6.00	0.00	11.00	41.00	54.91

Serial Number	Unscheduled Manhours				WUC 74XXX	
	Nov	Dec	Jan	Feb	Mar	Apr
0697	15.00	23.00	0.00	17.33	0.08	26.00
0698	22.50	34.50	0.00	0.00	14.75	31.33
0699	0.00	15.50	8.17	41.00	10.08	9.00
0700	3.00	36.75	10.08	2.00	12.25	31.17
0707	40.00	0.00	4.00	100.00	43.00	12.00
0709	5.00	18.00	0.00	49.50	18.75	3.00
0710	0.00	19.50	0.50	29.33	59.83	49.50
0711	3.00	26.00	15.00	20.00	13.00	1.50
0712	0.00	52.83	0.00	7.75	12.00	11.92
0713	13.83	28.00	0.00	0.00	3.00	0.00
0721	12.00	19.00	0.00	0.00	15.00	0.00
0722	21.00	13.00	0.00	89.08	49.75	0.00
0723	79.67	47.00	0.00	26.50	10.00	32.33
0731	11.83	32.50	0.00	13.00	25.33	31.58
0732	5.00	8.08	2.00	0.00	4.00	0.00
0737	4.00	0.00	16.00	14.42	23.00	0.00
0738	6.00	13.42	1.00	20.50	23.15	7.50
0757	18.00	9.00	0.00	34.50	26.08	4.00
0758	0.00	2.50	0.00	4.00	16.00	11.33
0759	0.00	0.00	0.00	0.00	15.00	73.17

Appendix C: Monthly Manhour Per Aircraft Histograms

```
                        SYMBOL  COUNT    MEAN     ST.DEV.
                          X      61     14.914    20.112
                        EACH SYMBOL REPRESENTS 1 OBSERVATION

                                                                  FREQUENCY PERCENTAGE
# OF ACFT ---->5    10   15   20   25   30   35   40   45   50   55   INT. CUM. INT.  CUM.
MANHOURS +----+----+----+----+----+----+----+----+----+----+----+
*-3.0000 +                                                         0    0   0.0   0.0
*0.00000 +XXXXXXXXXXXXXX                                          14   14  23.0  23.0
*3.00000 +XXXXXXXX                                                 8   22  13.1  36.1
*6.00000 +XXXXX                                                    5   27   8.2  44.3
*9.00000 +XXXX                                                     4   31   6.6  50.8
*12.0000 +XXX                                                      3   34   4.9  55.7
*15.0000 +XXXXXX                                                   6   40   9.8  65.6
*18.0000 +XXXXX                                                    5   45   8.2  73.8
*21.0000 +XXX                                                      3   48   4.9  78.7
*24.0000 +XXXX                                                     4   52   6.6  85.2
*27.0000 +X                                                        1   53   1.6  86.9
*30.0000 +                                                         0   53   0.0  86.9
*33.0000 +XX                                                       2   55   3.3  90.2
*36.0000 +                                                         0   55   0.0  90.2
*39.0000 +                                                         0   55   0.0  90.2
*42.0000 +XX                                                       2   57   3.3  93.4
*45.0000 +                                                         0   57   0.0  93.4
*48.0000 +                                                         0   57   0.0  93.4
*51.0000 +                                                         0   57   0.0  93.4
*54.0000 +                                                         0   57   0.0  93.4
*57.0000 +                                                         0   57   0.0  93.4
*60.0000 +                                                         0   57   0.0  93.4
*63.0000 +                                                         0   57   0.0  93.4
*66.0000 +X                                                        1   58   1.6  95.1
*69.0000 +                                                         0   58   0.0  95.1
*72.0000 +                                                         0   58   0.0  95.1
*75.0000 +                                                         0   58   0.0  95.1
*78.0000 +X                                                        1   59   1.6  96.7
*81.0000 +X                                                        1   60   1.6  98.4
*84.0000 +                                                         0   60   0.0  98.4
*87.0000 +                                                         0   60   0.0  98.4
*90.0000 +                                                         0   60   0.0  98.4
*93.0000 +                                                         0   60   0.0  98.4
*96.0000 +X                                                        1   61   1.6 100.0
*99.0000 +                                                         0   61   0.0 100.0
*102.000 +                                                         0   61   0.0 100.0
*105.000 +----+----+----+----+----+----+----+----+----+----+----+----+
              5   10   15   20   25   30   35   40   45   50   55   60
```

HISTOGRAM OF NOVEMBER MANHOURS PER AIRCRAFT VS NUMBER OF AIRCRAFT

```
                          SYMBOL   COUNT      MEAN      ST.DEV.
                            X        61      16.709     16.775
                          EACH SYMBOL REPRESENTS 1 OBSERVATION

                                                                        FREQUENCY  PERCENTAGE
# OF ACFT---> 5    10   15   20   25   30   35   40   45   50   55      INT.  CUM.  INT.  CUM.
MANHOURS +----+----+----+----+----+----+----+----+----+----+----+
*-3.0000 +                                                               0     0   0.0   0.0
*0.00000 +XXXXXXXXXXXX                                                  12    12  19.7  19.7
*3.00000 +XX                                                             2    14   3.3  23.0
*6.00000 +XXXX                                                           4    18   6.6  29.5
*9.00000 +XXXXXX                                                         6    24   9.8  39.3
*12.0000 +XXXXXX                                                         6    30   9.8  49.2
*15.0000 +XXXXX                                                          5    35   8.2  57.4
*18.0000 +XXXX                                                           4    39   6.6  63.9
*21.0000 +XX                                                             2    41   3.3  67.2
*24.0000 +XXX                                                            3    44   4.9  72.1
*27.0000 +XX                                                             2    46   3.3  75.4
*30.0000 +XXXX                                                           4    50   6.6  82.0
*33.0000 +XX                                                             2    52   3.3  85.2
*36.0000 +XXXX                                                           4    56   6.6  91.8
*39.0000 +XX                                                             2    58   3.3  95.1
*42.0000 +                                                               0    58   0.0  95.1
*45.0000 +                                                               0    58   0.0  95.1
*48.0000 +X                                                              1    59   1.6  96.7
*51.0000 +                                                               0    59   0.0  96.7
*54.0000 +X                                                              1    60   1.6  98.4
*57.0000 +                                                               0    60   0.0  98.4
*60.0000 +                                                               0    60   0.0  98.4
*63.0000 +                                                               0    60   0.0  98.4
*66.0000 +                                                               0    60   0.0  98.4
*69.0000 +                                                               0    60   0.0  98.4
*72.0000 +                                                               0    60   0.0  98.4
*75.0000 +                                                               0    60   0.0  98.4
*78.0000 +                                                               0    60   0.0  98.4
*81.0000 +                                                               0    60   0.0  98.4
*84.0000 +                                                               0    60   0.0  98.4
*87.0000 +                                                               0    60   0.0  98.4
*90.0000 +                                                               0    60   0.0  98.4
*93.0000 +                                                               0    60   0.0  98.4
*96.0000 +X                                                              1    61   1.6 100.0
*99.0000 +                                                               0    61   0.0 100.0
*102.000 +                                                               0    61   0.0 100.0
*105.000 +                                                               0    61   0.0 100.0
*108.000 +                                                               0    61   0.0 100.0
*111.000 +                                                               0    61   0.0 100.0
*LAST    +                                                               0    61   0.0 100.0
         +----+----+----+----+----+----+----+----+----+----+----+----+
              5   10   15   20   25   30   35   40   45   50   55   60

        HISTOGRAM OF DECEMBER MANHOURS PER AIRCRAFT VS NUMBER OF AIRCRAFT
```

```
                          SYMBOL  COUNT     MEAN     ST.DEV.
                            X       61      3.906    7.883
                          EACH SYMBOL REPRESENTS 1 OBSERVATION

                                                                    FREQUENCY PERCENTAGE
# OF ACFT---> 5    10   15   20   25   30   35   40   45   50   55    INT. CUM. INT.  CUM.
MANHOURS +----+----+----+----+----+----+----+----+----+----+----+
*-3.0000 +                                                             0    0   0.0   0.0
*0.00000 +XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX                         35   35  57.4  57.4
*3.00000 +XXXXXXXX                                                     8   43  13.1  70.5
*6.00000 +XXXX                                                         4   47   6.6  77.0
*9.00000 +XXXXX                                                        5   52   8.2  85.2
*12.0000 +XX                                                           2   54   3.3  88.5
*15.0000 +XXX                                                          3   57   4.9  93.4
*18.0000 +XX                                                           2   59   3.3  96.7
*21.0000 +X                                                            1   60   1.6  98.4
*24.0000 +                                                             0   60   0.0  98.4
*27.0000 +                                                             0   60   0.0  98.4
*30.0000 +                                                             0   60   0.0  98.4
*33.0000 +                                                             0   60   0.0  98.4
*36.0000 +                                                             0   60   0.0  98.4
*39.0000 +                                                             0   60   0.0  98.4
*42.0000 +                                                             0   60   0.0  98.4
*45.0000 +                                                             0   60   0.0  98.4
*48.0000 +                                                             0   60   0.0  98.4
*51.0000 +X                                                            1   61   1.6 100.0
*54.0000 +                                                             0   61   0.0 100.0
*57.0000 +                                                             0   61   0.0 100.0
*60.0000 +                                                             0   61   0.0 100.0
*63.0000 +                                                             0   61   0.0 100.0
*66.0000 +                                                             0   61   0.0 100.0
*69.0000 +                                                             0   61   0.0 100.0
*72.0000 +                                                             0   61   0.0 100.0
*75.0000 +                                                             0   61   0.0 100.0
*78.0000 +                                                             0   61   0.0 100.0
*81.0000 +                                                             0   61   0.0 100.0
*84.0000 +                                                             0   61   0.0 100.0
*87.0000 +                                                             0   61   0.0 100.0
*90.0000 +                                                             0   61   0.0 100.0
*93.0000 +                                                             0   61   0.0 100.0
*96.0000 +                                                             0   61   0.0 100.0
*99.0000 +                                                             0   61   0.0 100.0
*102.000 +                                                             0   61   0.0 100.0
*105.000 +                                                             0   61   0.0 100.0
*108.000 +                                                             0   61   0.0 100.0
*111.000 +                                                             0   61   0.0 100.0
*LAST    +                                                             0   61   0.0 100.0
         +----+----+----+----+----+----+----+----+----+----+----+----+
              5    10   15   20   25   30   35   40   45   50   55   60
```

HISTOGRAM OF JANUARY MANHOURS PER AIRCRAFT VS NUMBER OF AIRCRAFT

SYMBOL COUNT MEAN ST.DEV.
X 61 24.653 36.097
EACH SYMBOL REPRESENTS 1 OBSERVATION

# OF ACFT ---> 5 10 15 20 25 30 35 40 45 50 55		FREQUENCY INT.	FREQUENCY CUM.	PERCENTAGE INT.	PERCENTAGE CUM.
MANHOURS	+----+----+----+----+----+----+----+----+----+----+----+				
*-3.0000	+	0	0	0.0	0.0
*0.00000	+XXXXXXXXXXXXX	13	13	21.3	21.3
*3.00000	+XXXX	4	17	6.6	27.9
*6.00000	+XXXX	4	21	6.6	34.4
*9.00000	+XXX	3	24	4.9	39.3
*12.0000	+XX	2	26	3.3	42.6
*15.0000	+XXXXX	5	31	8.2	50.8
*18.0000	+XXX	3	34	4.9	55.7
*21.0000	+XX	2	36	3.3	59.0
*24.0000	+XXXXX	5	41	8.2	67.2
*27.0000	+XX	2	43	3.3	70.5
*30.0000	+XXXXX	5	48	8.2	78.7
*33.0000	+	0	48	0.0	78.7
*36.0000	+X	1	49	1.6	80.3
*39.0000	+X	1	50	1.6	82.0
*42.0000	+XX	2	52	3.3	85.2
*45.0000	+	0	52	0.0	85.2
*48.0000	+X	1	53	1.6	86.9
*51.0000	+XX	2	55	3.3	90.2
*54.0000	+	0	55	0.0	90.2
*57.0000	+	0	55	0.0	90.2
*60.0000	+	0	55	0.0	90.2
*63.0000	+X	1	56	1.6	91.8
*66.0000	+	0	56	0.0	91.8
*69.0000	+	0	56	0.0	91.8
*72.0000	+	0	56	0.0	91.8
*75.0000	+	0	56	0.0	91.8
*78.0000	+X	1	57	1.6	93.4
*81.0000	+	0	57	0.0	93.4
*84.0000	+	0	57	0.0	93.4
*87.0000	+	0	57	0.0	93.4
*90.0000	+X	1	58	1.6	95.1
*93.0000	+	0	58	0.0	95.1
*96.0000	+	0	58	0.0	95.1
*99.0000	+	0	58	0.0	95.1
*102.000	+X	1	59	1.6	96.7
*105.000	+X	1	60	1.6	98.4
*108.000	+	0	60	0.0	98.4
*111.000	+	0	60	0.0	98.4
*LAST	+X	1	61	1.6	100.0
	+----+----+----+----+----+----+----+----+----+----+----+----+				
	5 10 15 20 25 30 35 40 45 50 55 60				

HISTOGRAM OF FEBRUARY MANHOURS VS NUMBER OF AIRCRAFT

SYMBOL	COUNT	MEAN	ST.DEV.
X	61	30.960	25.937

EACH SYMBOL REPRESENTS 1 OBSERVATION

# OF ACFT---> 5 10 15 20 25 30 35 40 45 50 55		FREQUENCY INT.	FREQUENCY CUM.	PERCENTAGE INT.	PERCENTAGE CUM.
MANHOURS					
*-3.0000	+	0	0	0.0	0.0
*0.00000	+	0	0	0.0	0.0
*3.00000	+XXXX	4	4	6.6	6.6
*6.00000	+XX	2	6	3.3	9.8
*9.00000	+XXX	3	9	4.9	14.8
*12.0000	+XXXXXX	6	15	9.8	24.6
*15.0000	+XXXXXXX	7	22	11.5	36.1
*18.0000	+XXX	3	25	4.9	41.0
*21.0000	+XXX	3	28	4.9	45.9
*24.0000	+XXX	3	31	4.9	50.8
*27.0000	+XXXX	4	35	6.6	57.4
*30.0000	+XXXXX	5	40	8.2	65.6
*33.0000	+X	1	41	1.6	67.2
*36.0000	+	0	41	0.0	67.2
*39.0000	+X	1	42	1.6	68.9
*42.0000	+XX	2	44	3.3	72.1
*45.0000	+XXX	3	47	4.9	77.0
*48.0000	+X	1	48	1.6	78.7
*51.0000	+XX	2	50	3.3	82.0
*54.0000	+X	1	51	1.6	83.6
*57.0000	+X	1	52	1.6	85.2
*60.0000	+X	1	53	1.6	86.9
*63.0000	+	0	53	0.0	86.9
*66.0000	+	0	53	0.0	86.9
*69.0000	+XX	2	55	3.3	90.2
*72.0000	+	0	55	0.0	90.2
*75.0000	+XX	2	57	3.3	93.4
*78.0000	+	0	57	0.0	93.4
*81.0000	+	0	57	0.0	93.4
*84.0000	+	0	57	0.0	93.4
*87.0000	+	0	57	0.0	93.4
*90.0000	+	0	57	0.0	93.4
*93.0000	+X	1	58	1.6	95.1
*96.0000	+X	1	59	1.6	96.7
*99.0000	+	0	59	0.0	96.7
*102.000	+X	1	60	1.6	98.4
*105.000	+	0	60	0.0	98.4
*108.000	+X	1	61	1.6	100.0
*111.000	+	0	61	0.0	100.0
*LAST	+	0	61	0.0	100.0
	5 10 15 20 25 30 35 40 45 50 55 60 65				

HISTOGRAM OF MARCH MANHOURS VS NUMBER OF AIRCRAFT

SYMBOL	COUNT	MEAN	ST.DEV.
X	61	28.952	28.763

EACH SYMBOL REPRESENTS 1 OBSERVATION

# OF ACFT ---> MANHOURS	5 10 15 20 25 30 35 40 45 50 55	FREQUENCY INT.	FREQUENCY CUM.	PERCENTAGE INT.	PERCENTAGE CUM.
*-3.0000	+	0	0	0.0	0.0
*0.00000	+XXXXXXXXXXXXX	13	13	21.3	21.3
*3.00000	+XX	2	15	3.3	24.6
*6.00000	+XXX	3	18	4.9	29.5
*9.00000	+XXX	3	21	4.9	34.4
*12.0000	+XXXX	4	25	6.6	41.0
*15.0000	+	0	25	0.0	41.0
*18.0000	+X	1	26	1.6	42.6
*21.0000	+	0	26	0.0	42.6
*24.0000	+	0	26	0.0	42.6
*27.0000	+XXXXX	5	31	8.2	50.8
*30.0000	+XX	2	33	3.3	54.1
*33.0000	+XXXXX	5	38	8.2	62.3
*36.0000	+XX	2	40	3.3	65.6
*39.0000	+XXXX	4	44	6.6	72.1
*42.0000	+XX	2	46	3.3	75.4
*45.0000	+XX	2	48	3.3	78.7
*48.0000	+	0	48	0.0	78.7
*51.0000	+XX	2	50	3.3	82.0
*54.0000	+X	1	51	1.6	83.6
*57.0000	+XXX	3	54	4.9	88.5
*60.0000	+X	1	55	1.6	90.2
*63.0000	+	0	55	0.0	90.2
*66.0000	+	0	55	0.0	90.2
*69.0000	+	0	55	0.0	90.2
*72.0000	+	0	55	0.0	90.2
*75.0000	+X	1	56	1.6	91.8
*78.0000	+XX	2	58	3.3	95.1
*81.0000	+	0	58	0.0	95.1
*84.0000	+	0	58	0.0	95.1
*87.0000	+	0	58	0.0	95.1
*90.0000	+X	1	59	1.6	96.7
*93.0000	+	0	59	0.0	96.7
*96.0000	+	0	59	0.0	96.7
*99.0000	+X	1	60	1.6	98.4
*102.000	+	0	60	0.0	98.4
*105.000	+	0	60	0.0	98.4
*108.000	+	0	60	0.0	98.4
*111.000	+	0	60	0.0	98.4
*LAST	+X	1	61	1.6	100.0
	5 10 15 20 25 30 35 40 45 50 55 60				

HISTOGRAM OF APRIL MANHOURS VS NUMBER OF AIRCRAFT

Appendix D: Pooled Manhours Per Aircraft Histogram

```
                          SYMBOL  COUNT     MEAN     ST.DEV.
                            X      366     20.016    25.889
                          EACH X SYMBOL REPRESENTS 1 OBSERVATION
                         EACH # SYMBOL REPRESENTS 10 OBSERVATIONS

                                                                       FREQUENCY PERCENTAGE
# OF ACFT---> 5    10   15   20   25   30   35   40   45   50   55     INT. CUM. INT.  CUM.
MANHOURS +----+----+----+----+----+----+----+----+----+----+----+
*-3.0000 +                                                               0    0  0.0   0.0
*0.00000 +XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX####           87   87 23.8  23.8
*3.00000 +XXXXXXXXXXXXXXXXXXXXXXXXXXXX                                  28  115  7.7  31.4
*6.00000 +XXXXXXXXXXXXXXXXXXXXXX                                        22  137  6.0  37.4
*9.00000 +XXXXXXXXXXXXXXXXXXXXXXXX                                      24  161  6.6  44.0
*12.0000 +XXXXXXXXXXXXXXXXXXXXXXX                                       23  184  6.3  50.3
*15.0000 +XXXXXXXXXXXXXXXXXXXXXXXXXX                                    26  210  7.1  57.4
*18.0000 +XXXXXXXXXXXXXXXXXX                                            18  228  4.9  62.3
*21.0000 +XXXXXXXXXXX                                                   11  239  3.0  65.3
*24.0000 +XXXXXXXXXXXXXXX                                               15  254  4.1  69.4
*27.0000 +XXXXXXXXXXXXXX                                                14  268  3.8  73.2
*30.0000 +XXXXXXXXXXXXXXXX                                              16  284  4.4  77.6
*33.0000 +XXXXXXXXXX                                                    10  294  2.7  80.3
*36.0000 +XXXXXXX                                                        7  301  1.9  82.2
*39.0000 +XXXXXXXX                                                       8  309  2.2  84.4
*42.0000 +XXXXXXXX                                                       8  317  2.2  86.6
*45.0000 +XXXXX                                                          5  322  1.4  88.0
*48.0000 +XXX                                                            3  325   .8  88.8
*51.0000 +XXXXXXX                                                        7  332  1.9  90.7
*54.0000 +XXX                                                            3  335   .8  91.5
*57.0000 +XXXX                                                           4  339  1.1  92.6
*60.0000 +XX                                                             2  341   .5  93.2
*63.0000 +X                                                              1  342   .3  93.4
*66.0000 +X                                                              1  343   .3  93.7
*69.0000 +XX                                                             2  345   .5  94.3
*72.0000 +                                                               0  345  0.0  94.3
*75.0000 +XXX                                                            3  348   .8  95.1
*78.0000 +XXXX                                                           4  352  1.1  96.2
*81.0000 +X                                                              1  353   .3  96.4
*84.0000 +                                                               0  353  0.0  96.4
*87.0000 +                                                               0  353  0.0  96.4
*90.0000 +XX                                                             2  355   .5  97.0
*93.0000 +X                                                              1  356   .3  97.3
*96.0000 +XXX                                                            3  359   .8  98.1
*99.0000 +X                                                              1  360   .3  98.4
*102.000 +XX                                                             2  362   .5  98.9
         +----+----+----+----+----+----+----+----+----+----+----+----+
              5   10   15   20   25   30   35   40   45   50   55   60

              HISTOGRAM OF MANHOURS PER AIRCRAFT VS NUMBER OF AIRCRAFT
                                ALL MONTHS COMBINED
```

Appendix E: Manhour Paired Difference Histograms

```
                    SYMBOL  COUNT      MEAN     ST.DEV.
                      X       61      -1.795    20.520
                    EACH SYMBOL REPRESENTS 1 OBSERVATION

                                                               FREQUENCY PERCENTAGE
# OF ACFT---> 5    10   15   20   25   30   35   40   45   50   55   INT. CUM.  INT.  CUM.
MANHOURS +----+----+----+----+----+----+----+----+----+----+----+
*-49.000 +X                                                      1    1    1.6   1.6
*-45.500 +                                                       0    1    0.0   1.6
*-42.000 +                                                       0    1    0.0   1.6
*-38.500 +                                                       0    1    0.0   1.6
*-35.000 +                                                       0    1    0.0   1.6
*-31.500 +X                                                      1    2    1.6   3.3
*-28.000 +                                                       0    2    0.0   3.3
*-24.500 +X                                                      1    3    1.6   4.9
*-21.000 +XXXXX                                                  5    8    8.2  13.1
*-17.500 +XXXXXX                                                 6   14    9.8  23.0
*-14.000 +XXX                                                    3   17    4.9  27.9
*-10.500 +XXXX                                                   4   21    6.6  34.4
*-7.0000 +XXXXXXX                                                7   28   11.5  45.9
*-3.5000 +XX                                                     2   30    3.3  49.2
*0.00000 +XXXXXXX                                                7   37   11.5  60.7
*3.50000 +XXX                                                    3   40    4.9  65.6
*7.00000 +XXXX                                                   4   44    6.6  72.1
*10.5000 +XXXXX                                                  5   49    8.2  80.3
*14.0000 +XX                                                     2   51    3.3  83.6
*17.5000 +XX                                                     2   53    3.3  86.9
*21.0000 +XXX                                                    3   56    4.9  91.8
*24.5000 +                                                       0   56    0.0  91.8
*28.0000 +X                                                      1   57    1.6  93.4
*31.5000 +                                                       0   57    0.0  93.4
*35.0000 +X                                                      1   58    1.6  95.1
*38.5000 +                                                       0   58    0.0  95.1
*42.0000 +X                                                      1   59    1.6  96.7
*45.5000 +                                                       0   59    0.0  96.7
*49.0000 +                                                       0   59    0.0  96.7
*52.5000 +X                                                      1   60    1.6  98.4
*56.0000 +                                                       0   60    0.0  98.4
*59.5000 +                                                       0   60    0.0  98.4
*63.0000 +                                                       0   60    0.0  98.4
*66.5000 +                                                       0   60    0.0  98.4
*70.0000 +                                                       0   60    0.0  98.4
*73.5000 +                                                       0   60    0.0  98.4
*77.0000 +X                                                      1   61    1.6 100.0
*80.5000 +                                                       0   61    0.0 100.0
         +----+----+----+----+----+----+----+----+----+----+----+----+
              5    10   15   20   25   30   35   40   45   50   55   60
              HISTOGRAM OF MANHOUR PAIRED DIFFERENCES (NOV - DEC)
```

SYMBOL	COUNT	MEAN	ST.DEV.
X	61	11.00	21.483

EACH SYMBOL REPRESENTS 1 OBSERVATION

# OF ACFT—> MANHOURS	5 10 15 20 25 30 35 40 45 50 55	FREQUENCY INT.	FREQUENCY CUM.	PERCENTAGE INT.	PERCENTAGE CUM.
*-28.000	+	0	0	0.0	0.0
*-24.500	+X	1	1	1.6	1.6
*-21.000	+	0	1	0.0	1.6
*-17.500	+X	1	2	1.6	3.3
*-14.000	+	0	2	0.0	3.3
*-10.500	+XXX	3	5	4.9	8.2
*-7.0000	+XX	2	7	3.3	11.5
*-3.5000	+XXX	3	10	4.9	16.4
*0.00000	+XXXXXXXXXXXX	12	22	19.7	36.1
*3.50000	+XXXX	4	26	6.6	42.6
*7.00000	+XXXXXX	6	32	9.8	52.5
*10.5000	+XXX	3	35	4.9	57.4
*14.0000	+XXXXXX	6	41	9.8	67.2
*17.5000	+XXXXX	5	46	8.2	75.4
*21.0000	+XXXXX	5	51	8.2	83.6
*24.5000	+XXX	3	54	4.9	88.5
*28.0000	+	0	54	0.0	88.5
*31.5000	+	0	54	0.0	88.5
*35.0000	+X	1	55	1.6	90.2
*38.5000	+X	1	56	1.6	91.8
*42.0000	+X	1	57	1.6	93.4
*45.5000	+	0	57	0.0	93.4
*49.0000	+X	1	58	1.6	95.1
*52.5000	+	0	58	0.0	95.1
*56.0000	+	0	58	0.0	95.1
*59.5000	+	0	58	0.0	95.1
*63.0000	+	0	58	0.0	95.1
*66.5000	+	0	58	0.0	95.1
*70.0000	+	0	58	0.0	95.1
*73.5000	+	0	58	0.0	95.1
*77.0000	+X	1	59	1.6	96.7
*80.5000	+X	1	60	1.6	98.4
*84.0000	+	0	60	0.0	98.4
*87.5000	+	0	60	0.0	98.4
*91.0000	+	0	60	0.0	98.4
*94.5000	+X	1	61	1.6	100.0
*98.0000	+	0	61	0.0	100.0
*101.500	+	0	61	0.0	100.0
	5 10 15 20 25 30 35 40 45 50 55 60				

HISTOGRAM OF MANHOUR PAIRED DIFFERENCES (NOV - JAN)

SYMBOL	COUNT	MEAN	ST.DEV.
X	61	-9.739	40.916

EACH SYMBOL REPRESENTS 1 OBSERVATION

# OF ACFT----> 5 10 15 20 25 30 35 40 45 50 55		FREQUENCY INT.	FREQUENCY CUM.	PERCENTAGE INT.	PERCENTAGE CUM.
MANHOURS	+----+----+----+----+----+----+----+----+----+----+----+				
*-208.00	+X	1	1	1.6	1.6
*-200.00	+	0	1	0.0	1.6
*-192.00	+	0	1	0.0	1.6
*-184.00	+	0	1	0.0	1.6
*-176.00	+	0	1	0.0	1.6
*-168.00	+	0	1	0.0	1.6
*-160.00	+	0	1	0.0	1.6
*-152.00	+	0	1	0.0	1.6
*-144.00	+	0	1	0.0	1.6
*-136.00	+	0	1	0.0	1.6
*-128.00	+	0	1	0.0	1.6
*-120.00	+	0	1	0.0	1.6
*-112.00	+	0	1	0.0	1.6
*-104.00	+	0	1	0.0	1.6
*-96.000	+X	1	2	1.6	3.3
*-88.000	+	0	2	0.0	3.3
*-80.000	+	0	2	0.0	3.3
*-72.000	+X	1	3	1.6	4.9
*-64.000	+X	1	4	1.6	6.6
*-56.000	+XX	2	6	3.3	9.8
*-48.000	+	0	6	0.0	9.8
*-40.000	+XXX	3	9	4.9	14.8
*-32.000	+	0	9	0.0	14.8
*-24.000	+XXXXX	5	14	8.2	23.0
*-16.000	+XXXXXX	6	20	9.8	32.8
*-8.0000	+XXXXX	5	25	8.2	41.0
*0.00000	+XXXXXXXXXXXXXXXX	16	41	26.2	67.2
*8.00000	+XXXXX	5	46	8.2	75.4
*16.0000	+XXXXXX	6	52	9.8	85.2
*24.0000	+XXX	3	55	4.9	90.2
*32.0000	+	0	55	0.0	90.2
*40.0000	+XX	2	57	3.3	93.4
*48.0000	+	0	57	0.0	93.4
*56.0000	+X	1	58	1.6	95.1
*64.0000	+XX	2	60	3.3	98.4
*72.0000	+	0	60	0.0	98.4
*80.0000	+X	1	61	1.6	100.0
*88.0000	+	0	61	0.0	100.0
	+----+----+----+----+----+----+----+----+----+----+----+----+				
	5 10 15 20 25 30 35 40 45 50 55 60				

HISTOGRAM OF MANHOUR PAIRED DIFFERENCES (NOV - FEB)

SYMBOL	COUNT	MEAN	ST.DEV.
X	61	-16.046	33.058

EACH SYMBOL REPRESENTS 1 OBSERVATION

OF ACFT ---> 5 10 15 20 25 30 35 40 45 50 55

MANHOURS		FREQUENCY INT.	FREQUENCY CUM.	PERCENTAGE INT.	PERCENTAGE CUM.
*-114.00	+	0	0	0.0	0.0
*-108.00	+	0	0	0.0	0.0
*-102.00	+X	1	1	1.6	1.6
*-96.000	+	0	1	0.0	1.6
*-90.000	+XX	2	3	3.3	4.9
*-84.000	+X	1	4	1.6	6.6
*-78.000	+	0	4	0.0	6.6
*-72.000	+	0	4	0.0	6.6
*-66.000	+X	1	5	1.6	8.2
*-60.000	+	0	5	0.0	8.2
*-54.000	+XX	2	7	3.3	11.5
*-48.000	+XX	2	9	3.3	14.8
*-42.000	+XX	2	11	3.3	18.0
*-36.000	+X	1	12	1.6	19.7
*-30.000	+XX	2	14	3.3	23.0
*-24.000	+XXX	3	17	4.9	27.9
*-18.000	+XXX	3	20	4.9	32.8
*-12.000	+XXXXXXXX	8	28	13.1	45.9
*-6.0000	+XXXXXXXXXXXXX	13	41	21.3	67.2
*0.00000	+XXXXXX	6	47	9.8	77.0
*6.00000	+XXXXX	5	52	8.2	85.2
*12.0000	+XXXX	4	56	6.6	91.8
*18.0000	+XX	2	58	3.3	95.1
*24.0000	+	0	58	0.0	95.1
*30.0000	+	0	58	0.0	95.1
*36.0000	+X	1	59	1.6	96.7
*42.0000	+	0	59	0.0	96.7
*48.0000	+	0	59	0.0	96.7
*54.0000	+	0	59	0.0	96.7
*60.0000	+	0	59	0.0	96.7
*66.0000	+	0	59	0.0	96.7
*72.0000	+X	1	60	1.6	98.4
*78.0000	+	0	60	0.0	98.4
*84.0000	+	0	60	0.0	98.4
*90.0000	+X	1	61	1.6	100.0
*96.0000	+	0	61	0.0	100.0
*102.000	+	0	61	0.0	100.0
*108.000	+	0	61	0.0	100.0

5 10 15 20 25 30 35 40 45 50 55 60

HISTOGRAM OF PAIRED MANHOUR DIFFERENCES (NOV - MAR)

SYMBOL	COUNT	MEAN	ST.DEV.
X	61	-14.038	36.449

EACH SYMBOL REPRESENTS 1 OBSERVATION

# OF ACFT---> MANHOURS	5 10 15 20 25 30 35 40 45 50 55	FREQUENCY INT.	FREQUENCY CUM.	PERCENTAGE INT.	PERCENTAGE CUM.
*-120.00	+X	1	1	1.6	1.6
*-114.00	+	0	1	0.0	1.6
*-108.00	+	0	1	0.0	1.6
*-102.00	+	0	1	0.0	1.6
*-96.000	+	0	1	0.0	1.6
*-90.000	+	0	1	0.0	1.6
*-84.000	+	0	1	0.0	1.6
*-78.000	+XX	2	3	3.3	4.9
*-72.000	+XXX	3	6	4.9	9.8
*-66.000	+	0	6	0.0	9.8
*-60.000	+	0	6	0.0	9.8
*-54.000	+XX	2	8	3.3	13.1
*-48.000	+X	1	9	1.6	14.8
*-42.000	+XXX	3	12	4.9	19.7
*-36.000	+XXX	3	15	4.9	24.6
*-30.000	+XX	2	17	3.3	27.9
*-24.000	+XXXXX	5	22	8.2	36.1
*-18.000	+XXX	3	25	4.9	41.0
*-12.000	+XX	2	27	3.3	44.3
*-6.0000	+XXXXXXXX	8	35	13.1	57.4
*0.00000	+XXXX	4	39	6.6	63.9
*6.00000	+XXXX	4	43	6.6	70.5
*12.0000	+XXXX	4	47	6.6	77.0
*18.0000	+XXXXX	5	52	8.2	85.2
*24.0000	+XXXX	4	56	6.6	91.8
*30.0000	+X	1	57	1.6	93.4
*36.0000	+X	1	58	1.6	95.1
*42.0000	+X	1	59	1.6	96.7
*48.0000	+X	1	60	1.6	96.4
*54.0000	+	0	60	0.0	98.4
*60.0000	+	0	60	0.0	98.4
*66.0000	+	0	60	0.0	98.4
*72.0000	+	0	60	0.0	98.4
*78.0000	+	0	60	0.0	98.4
*84.0000	+	0	60	0.0	98.4
*90.0000	+	0	60	0.0	98.4
*96.0000	+X	1	61	1.6	100.0
*102.000	+	0	61	0.0	100.0
	5 10 15 20 25 30 35 40 45 50 55 60				

HISTOGRAM OF MANHOUR PAIRED DIFFERENCES (NOV - APR)

```
                         SYMBOL   COUNT      MEAN      ST.DEV.
                           X        61      12.803     19.468
                         EACH SYMBOL REPRESENTS 1 OBSERVATION

                                                                      FREQUENCY PERCENTAGE
# OF ACFT---> 5   10   15   20   25   30   35   40   45   50   55     INT. CUM.  INT. CUM.
MANHOURS +----+----+----+----+----+----+----+----+----+----+----+
*-44.000 +                                                              0    0   0.0   0.0
*-40.000 +X                                                             1    1   1.6   1.6
*-36.000 +                                                              0    1   0.0   1.6
*-32.000 +                                                              0    1   0.0   1.6
*-28.000 +                                                              0    1   0.0   1.6
*-24.000 +                                                              0    1   0.0   1.6
*-20.000 +                                                              0    1   0.0   1.6
*-16.000 +X                                                             1    2   1.6   3.3
*-12.000 +X                                                             1    3   1.6   4.9
*-8.0000 +X                                                             1    4   1.6   6.6
*-4.0000 +XXX                                                           3    7   4.9  11.5
*0.00000 +XXXXXXXXXX                                                   10   17  16.4  27.9
*4.00000 +XXXXX                                                         5   22   8.2  36.1
*8.00000 +XXXXXX                                                        6   28   9.8  45.9
*12.0000 +XXXX                                                          4   32   6.6  52.5
*16.0000 +XXXXXX                                                        6   38   9.8  62.3
*20.0000 +XXXXXXX                                                       7   45  11.5  73.8
*24.0000 +XXX                                                           3   48   4.9  78.7
*28.0000 +XX                                                            2   50   3.3  82.0
*32.0000 +XX                                                            2   52   3.3  85.2
*36.0000 +XXXXX                                                         5   57   8.2  93.4
*40.0000 +X                                                             1   58   1.6  95.1
*44.0000 +                                                              0   58   0.0  95.1
*48.0000 +X                                                             1   59   1.6  96.7
*52.0000 +                                                              0   59   0.0  96.7
*56.0000 +X                                                             1   60   1.6  98.4
*60.0000 +                                                              0   60   0.0  98.4
*64.0000 +                                                              0   60   0.0  98.4
*68.0000 +                                                              0   60   0.0  98.4
*72.0000 +                                                              0   60   0.0  98.4
*76.0000 +                                                              0   60   0.0  98.4
*80.0000 +                                                              0   60   0.0  98.4
*84.0000 +                                                              0   60   0.0  98.4
*88.0000 +                                                              0   60   0.0  98.4
*92.0000 +                                                              0   60   0.0  98.4
*96.0000 +X                                                             1   61   1.6 100.0
*100.000 +                                                              0   61   0.0 100.0
*104.000 +                                                              0   61   0.0 100.0
         +----+----+----+----+----+----+----+----+----+----+----+----+
              5   10   15   20   25   30   35   40   45   50   55   60
```

HISTOGRAM OF MANHOUR PAIRED DIFFERENCES (DEC - JAN)

```
                    SYMBOL   COUNT      MEAN      ST.DEV.
                      X        61      -7.945     38.685
                    EACH SYMBOL REPRESENTS 1 OBSERVATION

                                                                        FREQUENCY PERCENTAGE
# OF ACFT---> 5    10   15   20   25   30   35   40   45   50   55      INT. CUM.  INT. CUM.
MANHOURS +----+----+----+----+----+----+----+----+----+----+----+
*-192.00 +X                                                               1    1    1.6   1.6
*-184.00 +                                                                0    1    0.0   1.6
*-176.00 +                                                                0    1    0.0   1.6
*-168.00 +                                                                0    1    0.0   1.6
*-160.00 +                                                                0    1    0.0   1.6
*-152.00 +                                                                0    1    0.0   1.6
*-144.00 +                                                                0    1    0.0   1.6
*-136.00 +                                                                0    1    0.0   1.6
*-128.00 +                                                                0    1    0.0   1.6
*-120.00 +                                                                0    1    0.0   1.6
*-112.00 +                                                                0    1    0.0   1.6
*-104.00 +                                                                0    1    0.0   1.6
*-96.000 +X                                                               1    2    1.6   3.3
*-88.000 +                                                                0    2    0.0   3.3
*-80.000 +                                                                0    2    0.0   3.3
*-72.000 +XX                                                              2    4    3.3   6.6
*-64.000 +                                                                0    4    0.0   6.6
*-56.000 +X                                                               1    5    1.6   8.2
*-48.000 +                                                                0    5    0.0   8.2
*-40.000 +X                                                               1    6    1.6   9.8
*-32.000 +XX                                                              2    8    3.3  13.1
*-24.000 +XXXXXXX                                                         7   15   11.5  24.6
*-16.000 +XXXX                                                            4   19    6.6  31.1
*-8.0000 +XXXXXX                                                          6   25    9.8  41.0
*0.00000 +XXXXXXXXXX                                                     10   35   16.4  57.4
*8.00000 +XXXXXXXX                                                        8   43   13.1  70.5
*16.0000 +XXXXX                                                           5   48    8.2  78.7
*24.0000 +XXXXX                                                           5   53    8.2  86.9
*32.0000 +XXX                                                             3   56    4.9  91.8
*40.0000 +XXX                                                             3   59    4.9  96.7
*48.0000 +X                                                               1   60    1.6  98.4
*56.0000 +                                                                0   60    0.0  98.4
*64.0000 +                                                                0   60    0.0  98.4
*72.0000 +                                                                0   60    0.0  98.4
*80.0000 +                                                                0   60    0.0  98.4
*88.0000 +X                                                               1   61    1.6 100.0
*96.0000 +                                                                0   61    0.0 100.0
*104.000 +                                                                0   61    0.0 100.0
         +----+----+----+----+----+----+----+----+----+----+----+----+
              5    10   15   20   25   30   35   40   45   50   55   60

              HISTOGRAM OF MANHOUR PAIRED DIFFERENCES (DEC - FEB)
```

```
        SYMBOL   COUNT     MEAN      ST.DEV.
          X        61     -14.251    30.814
        EACH SYMBOL REPRESENTS 1 OBSERVATION

                                                                    FREQUENCY PERCENTAGE
# OF ACFT---> 5   10   15   20   25   30   35   40   45   50   55   INT. CUM.  INT.  CUM.
MANHOURS +----+----+----+----+----+----+----+----+----+----+----+
*-100.00 +X                                                           1    1   1.6   1.6
*-96.000 +                                                            0    1   0.0   1.6
*-92.000 +X                                                           1    2   1.6   3.3
*-88.000 +                                                            0    2   0.0   3.3
*-84.000 +                                                            0    2   0.0   3.3
*-80.000 +                                                            0    2   0.0   3.3
*-76.000 +                                                            0    2   0.0   3.3
*-72.000 +                                                            0    2   0.0   3.3
*-68.000 +                                                            0    2   0.0   3.3
*-64.000 +XXXX                                                        4    6   6.6   9.8
*-60.000 +X                                                           1    7   1.6  11.5
*-56.000 +                                                            0    7   0.0  11.5
*-52.000 +                                                            0    7   0.0  11.5
*-48.000 +X                                                           1    8   1.6  13.1
*-44.000 +X                                                           1    9   1.6  14.8
*-40.000 +XXXX                                                        4   13   6.6  21.3
*-36.000 +XX                                                          2   15   3.3  24.6
*-32.000 +XX                                                          2   17   3.3  27.9
*-28.000 +X                                                           1   18   1.6  29.5
*-24.000 +                                                            0   18   0.0  29.5
*-20.000 +XXX                                                         3   21   4.9  34.4
*-16.000 +XXXX                                                        4   25   6.6  41.0
*-12.000 +XX                                                          2   27   3.3  44.3
*-8.0000 +XXXXX                                                       5   32   8.2  52.5
*-4.0000 +XXXX                                                        4   36   6.6  59.0
*0.00000 +XXXXXX                                                      6   42   9.8  68.9
*4.00000 +X                                                           1   43   1.6  70.5
*8.00000 +XXX                                                         3   46   4.9  75.4
*12.0000 +XXX                                                         3   49   4.9  80.3
*16.0000 +XXXX                                                        4   53   6.6  86.9
*20.0000 +X                                                           1   54   1.6  88.5
*24.0000 +XX                                                          2   56   3.3  91.8
*28.0000 +XXX                                                         3   59   4.9  96.7
*32.0000 +                                                            0   59   0.0  96.7
*36.0000 +                                                            0   59   0.0  96.7
*40.0000 +X                                                           1   60   1.6  98.4
*44.0000 +X                                                           1   61   1.6 100.0
*48.0000 +                                                            0   61   0.0 100.0
         +----+----+----+----+----+----+----+----+----+----+----+----+
              5   10   15   20   25   30   35   40   45   50   55   60
```

HISTOGRAM OF MANHOUR PAIRED DIFFERENCES (DEC - MAR)

SYMBOL	COUNT	MEAN	ST.DEV.
X	61	-12.243	32.106

EACH SYMBOL REPRESENTS 1 OBSERVATION

# OF ACFT---> MANHOURS	5 10 15 20 25 30 35 40 45 50 55	FREQUENCY INT.	FREQUENCY CUM.	PERCENTAGE INT.	PERCENTAGE CUM.
*-144.00	+	0	0	0.0	0.0
*-138.00	+	0	0	0.0	0.0
*-132.00	+X	1	1	1.6	1.6
*-126.00	+	0	1	0.0	1.6
*-120.00	+	0	1	0.0	1.6
*-114.00	+	0	1	0.0	1.6
*-108.00	+	0	1	0.0	1.6
*-102.00	+	0	1	0.0	1.6
*-96.000	+	0	1	0.0	1.6
*-90.000	+	0	1	0.0	1.6
*-84.000	+	0	1	0.0	1.6
*-78.000	+	0	1	0.0	1.6
*-72.000	+XXX	3	4	4.9	6.6
*-66.000	+	0	4	0.0	6.6
*-60.000	+X	1	5	1.6	8.2
*-54.000	+X	1	6	1.6	9.8
*-48.000	+X	1	7	1.6	11.5
*-42.000	+XX	2	9	3.3	14.8
*-36.000	+XX	2	11	3.3	18.0
*-30.000	+XXX	3	14	4.9	23.0
*-24.000	+XXXXXX	6	20	9.8	32.8
*-18.000	+XX	2	22	3.3	36.1
*-12.000	+XXXX	4	26	6.6	42.6
*-6.0000	+XXXXXX	6	32	9.8	52.5
*0.00000	+XXXXXXX	7	39	11.5	63.9
*6.00000	+XXXXXX	6	45	9.8	73.8
*12.0000	+XXXX	4	49	6.6	80.3
*18.0000	+XXXXX	5	54	8.2	88.5
*24.0000	+X	1	55	1.6	90.2
*30.0000	+XXX	3	58	4.9	95.1
*36.0000	+X	1	59	1.6	96.7
*42.0000	+X	1	60	1.6	98.4
*48.0000	+	0	60	0.0	98.4
*54.0000	+X	1	61	1.6	100.0
*60.0000	+	0	61	0.0	100.0
*66.0000	+	0	61	0.0	100.0
*72.0000	+	0	61	0.0	100.0
*78.0000	+	0	61	0.0	100.0
	5 10 15 20 25 30 35 40 45 50 55 60				

HISTOGRAM OF MANHOUR PAIRED DIFFERENCES (DEC - APR)

SYMBOL COUNT MEAN ST.DEV.
X 61 -20.748 37.402
EACH SYMBOL REPRESENTS 1 OBSERVATION

# OF ACFT---> 5 10 15 20 25 30 35 40 45 50 55		FREQUENCY INT.	FREQUENCY CUM.	PERCENTAGE INT.	PERCENTAGE CUM.
MANHOURS	+----+----+----+----+----+----+----+----+----+----+----+				
*-224.00	+X	1	1	1.6	1.6
*-217.00	+	0	1	0.0	1.6
*-210.00	+	0	1	0.0	1.6
*-203.00	+	0	1	0.0	1.6
*-196.00	+	0	1	0.0	1.6
*-189.00	+	0	1	0.0	1.6
*-182.00	+	0	1	0.0	1.6
*-175.00	+	0	1	0.0	1.6
*-168.00	+	0	1	0.0	1.6
*-161.00	+	0	1	0.0	1.6
*-154.00	+	0	1	0.0	1.6
*-147.00	+	0	1	0.0	1.6
*-140.00	+	0	1	0.0	1.6
*-133.00	+	0	1	0.0	1.6
*-126.00	+	0	1	0.0	1.6
*-119.00	+	0	1	0.0	1.6
*-112.00	+	0	1	0.0	1.6
*-105.00	+	0	1	0.0	1.6
*-98.000	+X	1	2	1.6	3.3
*-91.000	+X	1	3	1.6	4.9
*-84.000	+X	1	4	1.6	6.6
*-77.000	+X	1	5	1.6	8.2
*-70.000	+	0	5	0.0	8.2
*-63.000	+	0	5	0.0	8.2
*-56.000	+	0	5	0.0	8.2
*-49.000	+XXX	3	8	4.9	13.1
*-42.000	+	0	8	0.0	13.1
*-35.000	+X	1	9	1.6	14.8
*-28.000	+XXXXXXXXX	9	18	14.8	29.5
*-21.000	+XXX	3	21	4.9	34.4
*-14.000	+XXXXXXXX	8	29	13.1	47.5
*-7.0000	+XXXXXX	6	35	9.8	57.4
*0.00000	+XXXXXXXXXXXXXXX	15	50	24.6	82.0
*7.00000	+XXXXXX	6	56	9.8	91.8
*14.0000	+XX	2	58	3.3	95.1
*21.0000	+XX	2	60	3.3	98.4
*28.0000	+X	1	61	1.6	100.0
*35.0000	+	0	61	0.0	100.0
	+----+----+----+----+----+----+----+----+----+----+----+----+				
	5 10 15 20 25 30 35 40 45 50 55 60				

HISTOGRAM OF MANHOUR PAIRED DIFFERENCES (JAN - FEB)

```
                    SYMBOL  COUNT     MEAN      ST.DEV.
                      X      61     -27.054     26.671
                    EACH SYMBOL REPRESENTS 1 OBSERVATION

                                                                      FREQUENCY PERCENTAGE
# OF ACFT---> 5    10   15   20   25   30   35   40   45   50   55    INT. CUM.  INT.  CUM.
MANHOURS +----+----+----+----+----+----+----+----+----+----+----+
*-104.00 +X                                                            1    1    1.6   1.6
*-100.00 +X                                                            1    2    1.6   3.3
*-96.000 +                                                             0    2    0.0   3.3
*-92.000 +                                                             0    2    0.0   3.3
*-88.000 +                                                             0    2    0.0   3.3
*-84.000 +X                                                            1    3    1.6   4.9
*-80.000 +X                                                            1    4    1.6   6.6
*-76.000 +                                                             0    4    0.0   6.6
*-72.000 +XX                                                           2    6    3.3   9.8
*-68.000 +                                                             0    6    0.0   9.8
*-64.000 +X                                                            1    7    1.6  11.5
*-60.000 +                                                             0    7    0.0  11.5
*-56.000 +X                                                            1    8    1.6  13.1
*-52.000 +XX                                                           2   10    3.3  16.4
*-48.000 +X                                                            1   11    1.6  18.0
*-44.000 +XX                                                           2   13    3.3  21.3
*-40.000 +XXX                                                          3   16    4.9  26.2
*-36.000 +X                                                            1   17    1.6  27.9
*-32.000 +XX                                                           2   19    3.3  31.1
*-28.000 +X                                                            1   20    1.6  32.8
*-24.000 +XXXXXXX                                                      7   27   11.5  44.3
*-20.000 +XXXX                                                         4   31    6.6  50.8
*-16.000 +XXXXXX                                                       6   37    9.8  60.7
*-12.000 +XXXXX                                                        5   42    8.2  68.9
*-8.0000 +XXXXXX                                                       6   48    9.8  78.7
*-4.0000 +XXXX                                                         4   52    6.6  85.2
*0.00000 +XXXXXXX                                                      7   59   11.5  96.7
*4.00000 +X                                                            1   60    1.6  98.4
*8.00000 +                                                             0   60    0.0  98.4
*12.0000 +                                                             0   60    0.0  98.4
*16.0000 +                                                             0   60    0.0  98.4
*20.0000 +                                                             0   60    0.0  98.4
*24.0000 +                                                             0   60    0.0  98.4
*28.0000 +                                                             0   60    0.0  98.4
*32.0000 +                                                             0   60    0.0  98.4
*36.0000 +                                                             0   60    0.0  98.4
*40.0000 +X                                                            1   61    1.6 100.0
*44.0000 +                                                             0   61    0.0 100.0
         +----+----+----+----+----+----+----+----+----+----+----+----+
              5   10   15   20   25   30   35   40   45   50   55   60
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HISTOGRAM OF MANHOUR PAIRED DIFFERENCES (JAN - MAR)

```
               SYMBOL  COUNT      MEAN      ST.DEV.
                 X       61     -20.748     37.402
               EACH SYMBOL REPRESENTS 1 OBSERVATION

                                                                         FREQUENCY PERCENTAGE
# OF ACFT---> 5    10   15   20   25   30   35   40   45   50   55      INT.  CUM.  INT.  CUM.
MANHOURS  +----+----+----+----+----+----+----+----+----+----+----+
*-224.00  +X                                                             1     1    1.6   1.6
*-217.00  +                                                              0     1    0.0   1.6
*-210.00  +                                                              0     1    0.0   1.6
*-203.00  +                                                              0     1    0.0   1.6
*-196.00  +                                                              0     1    0.0   1.6
*-189.00  +                                                              0     1    0.0   1.6
*-182.00  +                                                              0     1    0.0   1.6
*-175.00  +                                                              0     1    0.0   1.6
*-168.00  +                                                              0     1    0.0   1.6
*-161.00  +                                                              0     1    0.0   1.6
*-154.00  +                                                              0     1    0.0   1.6
*-147.00  +                                                              0     1    0.0   1.6
*-140.00  +                                                              0     1    0.0   1.6
*-133.00  +                                                              0     1    0.0   1.6
*-126.00  +                                                              0     1    0.0   1.6
*-119.00  +                                                              0     1    0.0   1.6
*-112.00  +                                                              0     1    0.0   1.6
*-105.00  +                                                              0     1    0.0   1.6
*-98.000  +X                                                             1     2    1.6   3.3
*-91.000  +X                                                             1     3    1.6   4.9
*-84.000  +X                                                             1     4    1.6   6.6
*-77.000  +X                                                             1     5    1.6   8.2
*-70.000  +                                                              0     5    0.0   8.2
*-63.000  +                                                              0     5    0.0   8.2
*-56.000  +                                                              0     5    0.0   8.2
*-49.000  +XXX                                                           3     8    4.9  13.1
*-42.000  +                                                              0     8    0.0  13.1
*-35.000  +X                                                             1     9    1.6  14.8
*-28.000  +XXXXXXXXX                                                     9    18   14.8  29.5
*-21.000  +XXX                                                           3    21    4.9  34.4
*-14.000  +XXXXXXXX                                                      8    29   13.1  47.5
*-7.0000  +XXXXXX                                                        6    35    9.8  57.4
*0.00000  +XXXXXXXXXXXXXXX                                              15    50   24.6  82.0
*7.00000  +XXXXXX                                                        6    56    9.8  91.8
*14.0000  +XX                                                            2    58    3.3  95.1
*21.0000  +XX                                                            2    60    3.3  98.4
*28.0000  +X                                                             1    61    1.6 100.0
*35.0000  +                                                              0    61    0.0 100.0
          +----+----+----+----+----+----+----+----+----+----+----+----+
               5   10   15   20   25   30   35   40   45   50   55   60
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HISTOGRAM OF MANHOUR PAIRED DIFFERENCES (JAN - APR)

```
                    SYMBOL   COUNT      MEAN      ST.DEV.
                      X        61      -6.307     37.620
                    EACH SYMBOL REPRESENTS 1 OBSERVATION

                                                                     FREQUENCY PERCENTAGE
# OF ACFT---> 5    10   15   20   25   30   35   40   45   50   55    INT. CUM.  INT. CUM.
MANHOURS +----+----+----+----+----+----+----+----+----+----+----+
*-84.000 +                                                             0    0    0.0   0.0
*-78.000 +X                                                            1    1    1.6   1.6
*-72.000 +X                                                            1    2    1.6   3.3
*-66.000 +X                                                            1    3    1.6   4.9
*-60.000 +XXX                                                          3    6    4.9   9.8
*-54.000 +                                                             0    6    0.0   9.8
*-48.000 +X                                                            1    7    1.6  11.5
*-42.000 +XX                                                           2    9    3.3  14.8
*-36.000 +                                                             0    9    0.0  14.8
*-30 00 +XXXXX                                                         5   14    8.2  23.0
*-24.000 +XXX                                                          3   17    4.9  27.9
*-18.000 +X                                                            1   18    1.6  29.5
*-12.000 +XXXXXXX                                                      7   25   11.5  41.0
*-6.0000 +XXXXXXXXXXX                                                 11   36   18.0  59.0
*0.00000 +XXXXXX                                                       6   42    9.8  68.9
*6.00000 +                                                             0   42    0.0  68.9
*12.0000 +XXXX                                                         4   46    6.6  75.4
*18.0000 +XXXXXX                                                       6   52    9.8  85.2
*24.0000 +                                                             0   52    0.0  85.2
*30.0000 +X                                                            1   53    1.6  86.9
*36.0000 +XX                                                           2   55    3.3  90.2
*42.00                                                                 2   57    3.3  93.4
*48.0000 +                                                             0   57    0.0  93.4
*54.0000 +                                                             0   57    0.0  93.4
*60.0000 +X                                                            1   58    1.6  95.1
*66.0000 +X                                                            1   59    1.6  96.7
*72.0000 +                                                             0   59    0.0  96.7
*78.0000 +                                                             0   59    0.0  96.7
*84.0000 +                                                             0   59    0.0  96.7
*90.0000 +                                                             0   59    0.0  96.7
*96.0000 +                                                             0   59    0.0  96.7
*102.000 +X                                                            1   60    1.6  98.4
*108.000 +                                                             0   60    0.0  98.4
*114.000 +                                                             0   60    0.0  98.4
*120.000 +                                                             0   60    0.0  98.4
*126.000 +                                                             0   60    0.0  98.4
*132.000 +X                                                            1   61    1.6 100.0
*138.000 +                                                             0   61    0.0 100.0
         +----+----+----+----+----+----+----+----+----+----+----+----+
              5   10   15   20   25   30   35   40   45   50   55   60
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HISTOGRAM OF MANHOUR PAIRED DIFFERENCES (FEB - MAR)

SYMBOL COUNT MEAN ST.DEV.
X 61 -4.299 46.124
EACH SYMBOL REPRESENTS 1 OBSERVATION

# OF ACFT ——> / MANHOURS	5 10 15 20 25 30 35 40 45 50 55	FREQUENCY INT.	FREQUENCY CUM.	PERCENTAGE INT.	PERCENTAGE CUM.
*-160.00	+	0	0	0.0	0.0
*-150.00	+	0	0	0.0	0.0
*-140.00	+	0	0	0.0	0.0
*-130.00	+X	1	1	1.6	1.6
*-120.00	+	0	1	0.0	1.6
*-110.00	+	0	1	0.0	1.6
*-100.00	+	0	1	0.0	1.6
*-90.000	+X	1	2	1.6	3.3
*-80.000	+	0	2	0.0	3.3
*-70.000	+XX	2	4	3.3	6.6
*-60.000	+X	1	5	1.6	8.2
*-50.000	+X	1	6	1.6	9.8
*-40.000	+XX	2	8	3.3	13.1
*-30.000	+XXXXX	5	13	8.2	21.3
*-20.000	+XXXXXXXXXXX	11	24	18.0	39.3
*-10.000	+XXXX	4	28	6.6	45.9
*0.00000	+XXXXXXXXX	9	37	14.8	60.7
*10.0000	+X	1	38	1.6	62.3
*20.0000	+XXXXXXXX	8	46	13.1	75.4
*30.0000	+XXXXXX	6	52	9.8	85.2
*40.0000	+XX	2	54	3.3	88.5
*50.0000	+XXX	3	57	4.9	93.4
*60.0000	+	0	57	0.0	93.4
*70.0000	+X	1	58	1.6	95.1
*80.0000	+	0	58	0.0	95.1
*90.0000	+XX	2	60	3.3	98.4
*100.000	+	0	60	0.0	98.4
*110.000	+	0	60	0.0	98.4
*120.000	+	0	60	0.0	98.4
*130.000	+	0	60	0.0	98.4
*140.000	+	0	60	0.0	98.4
*150.000	+	0	60	0.0	98.4
*160.000	+	0	60	0.0	98.4
*170.000	+	0	60	0.0	98.4
*180.000	+X	1	61	1.6	100.0
*190.000	+	0	61	0.0	100.0
*200.000	+	0	61	0.0	100.0
*210.000	+	0	61	0.0	100.0
	5 10 15 20 25 30 35 40 45 50 55 60				

HISTOGRAM OF MANHOUR PAIRED DIFFERENCES (FEB - APR)

SYMBOL	COUNT	MEAN	ST.DEV.
X	61	2.008	32.829

EACH SYMBOL REPRESENTS 1 OBSERVATION

# OF ACFT---> MANHOURS	5 10 15 20 25 30 35 40 45 50 55	FREQUENCY INT.	FREQUENCY CUM.	PERCENTAGE INT.	PERCENTAGE CUM.
*-70.000	+X	1	1	1.6	1.6
*-65.000	+XX	2	3	3.3	4.9
*-60.000	+X	1	4	1.6	6.6
*-55.000	+X	1	5	1.6	8.2
*-50.000	+X	1	6	1.6	9.8
*-45.000	+	0	6	0.0	9.8
*-40.000	+	0	6	0.0	9.8
*-35.000	+	0	6	0.0	9.8
*-30.000	+	0	6	0.0	9.8
*-25.000	+XXX	3	9	4.9	14.8
*-20.000	+XXXXX	5	14	8.2	23.0
*-15.000	+XXXX	4	18	6.6	29.5
*-10.000	+X	1	19	1.6	31.1
*-5.0000	+XX	2	21	3.3	34.4
*0.00000	+XX	2	23	3.3	37.7
*5.00000	+XXXXXXXXXXXXX	13	36	21.3	59.0
*10.0000	+X	1	37	1.6	60.7
*15.0000	+XXX	3	40	4.9	65.6
*20.0000	+XXXXXX	6	46	9.8	75.4
*25.0000	+XXX	3	49	4.9	80.3
*30.0000	+XXX	3	52	4.9	85.2
*35.0000	+XX	2	54	3.3	88.5
*40.0000	+X	1	55	1.6	90.2
*45.0000	+XX	2	57	3.3	93.4
*50.0000	+X	1	58	1.6	95.1
*55.0000	+	0	58	0.0	95.1
*60.0000	+X	1	59	1.6	96.7
*65.0000	+X	1	60	1.6	98.4
*70.0000	+	0	60	0.0	98.4
*75.0000	+	0	60	0.0	98.4
*80.0000	+	0	60	0.0	98.4
*85.0000	+	0	60	0.0	98.4
*90.0000	+	0	60	0.0	98.4
*95.0000	+	0	60	0.0	98.4
*100.000	+	0	60	0.0	98.4
*105.000	+	0	60	0.0	98.4
*110.000	+X	1	61	1.6	100.0
*115.000	+	0	61	0.0	100.0
	5 10 15 20 25 30 35 40 45 50 55 60				

HISTOGRAM OF MANHOUR PAIRED DIFFERENCES (MAR - APR)

Bilbliography

1. Air Force Audit Agency. Summary Report of Audit, Maintenance Data Collection (MDC) System Modification Project. Report Number 85419. Norton AFB CA: Air Force Audit Agency, 9 January 1979.

2. Air Force Data Systems Design Center. Core Automated Maintenance System. System Specification SS-G83-44. Gunter AFS AL: Standard Automated Systems Center, 17 February 1984.

3. Air Force Logistics Command. Product Performance. AFLCR 66-15. Wright-Patterson AFB OH: HQ AFLC, 2 July 1980.

4. -----. An Evaluation of the WSSC Cost Allocation Algorithms, Volume I: Overview. Wright-Patterson AFB OH: HQ AFLC, May 1983 (AD-A142 366).

5. Air Force Logistics Management Center. Estimating Direct Labor Hours by Sampling: A Pilot Demonstration Report. AFLMC Project Number 770401. Gunter AFS AL: AFLMC, 31 October 1978.

6. -----. Reducing Base Level Maintenance Data Collection System (MDCS) Costs. AFLMC Report Number 820202-1. Gunter AFS AL: AFLMC, 1 February 1982.

7. Air Force Management Engineering Agency. LCOM II Student Training Guide. AFMSMMET Report Number 81-2. Wright-Patterson AFB OH: AFMEA, 31 December 1981.

8. Badalmente, Major Richard V., and Lieutenant Colonel Thomas D. Clark, Jr. Spinning Our [Information] Wheels: A Look At the Maintenance Data Collection System. Technical Report, AU-AFIT-LSTR-1-78. School of Systems and Logistics, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, February 1978.

9. Creasy, Michael. HQ/MAC Logistics Plans Office. Telephone interviews. Scott AFB IL: HQ MAC/LGX, 15-31 May 1985.

10. Department of the Air Force. Air Force Management Engineering Program, Logistics Composite Modeling. AFR 25-5, Volume IV (Draft Revision). Washington: HQ USAF, undated.

11. -----. General Accounting and Finance Systems at Base Level (PA). AFR 177-101. Washington: HQ USAF, 1 February 1984.

12. -----. The Maintenance Data Collection System. AFTO 00-20-2. Washington: HQ USAF, 1 February 1981.

13. -----. Visibility and Management of Operating and Support Cost Program (VAMOSC). AFR 400-31, Volume II. Washington: HQ USAF, 24 August 1982.

14. -----. Visibility and Management of Operating and Support Cost Program (VAMOSC). AFR 400-31, Volume IV. Washington: HQ USAF, 6 August 1982.

15. Department of the Army. Aviation Unscheduled Maintenance Sample Data Collection Users Guide. St. Louis: U. S. Army Aviation Systems Command, January 1983.

16. -----. Sample Data Collection (SDC). AR 750-37 (Draft Revision). Lexington KY: USAMC Material Readiness Support Activity, 20 November 1984.

17. -----. Sample Data Collection Plan, UMSDC, Unscheduled Maintenance Sample Data Collection Plan. Aviation Applications Guide, Volume I. St. Louis: U. S. Army Aviation Systems Command, April 1984.

18. -----. Sample Data Collection Plan, UMSDC, Unscheduled Maintenance Sample Data Collection Plan. Aviation Applications Guide, Volume II. St. Louis: U. S. Army Aviation Systems Command, April 1984.

19. -----. Sample Data Collection Program Summary, FY 84. RCS: DRCMM 156. Lexington KY: USAMC Material Readiness Support Activity, 3 December 1984.

20. Emory, C. William. Business Research Methods (Second Edition). Homewood IL: Richard D. Irwin, Inc., 1980.

21. Garamone, Jim. "New Computer Being Tested for Use in Maintenance Field," Air Force Times, Vol 46: 16 (March 18, 1985)

22. General Accounting Office. The Air Force Can Improve It's Maintenance Information Systems. GAO Report Number 83-20. Washington: Government Printing Office, January 1983.

23. Gross, Charles W. Integrated Maintenance Management Office. Personal interviews. HQ AFLC, Wright-Patterson AFB OH, 15 January-31 July 1985.

24. -----. Briefing materials concerning the Product Performance System (D056). HQ AFLC, Wright-Patterson AFB OH, 1984.

25. Hall, Fred M. "Economic Analysis for Data Base Management," 1982 Proceedings Annual Reliability and Maintainability Symposium. 343-345. IEEE Press, New York, 1982.

26. Hollander, Myles, and Douglas A. Wolfe. Non-Parametric Statistical Methods. New York: John Wiley & Sons, 1973.

27. McClave, James T., and P. George Benson. Statistics For Business and Economics (Second Edition). San Francisco: Dellen Publishing Company, 1982.

28. Mills, Stephen E. Air Force Maintenance and Supply Manpower Management Engineering Team, LCOM Branch. Personal interviews. AFMSMMET, Wright Patterson AFB, OH, 15 January-31 May 1985.

29. Office of the Assistant Secretary of Defense. IDA/OSD Reliability and Maintainability Study, Core Group Report. Contract MDA903-79-C0018. Institute for Defense Analyses, Washington: OASD, November 1983 (AD-A142 569).

30. Recktenwalt, Major Thomas J. "The Air Force Visibility and Management of Operating and Support Costs; A Practical Approach to O&S Costing." Presented to 17th Annual DOD Cost Analysis Symposium. Arlington VA, September 1982 (AD-A125 986).

31. "The United States Air Force in Facts and Figures: An Air Force Almanac," Air Force Magazine, Vol 68: 189 (May 1985).

32. Yamane, Taro. Elementary Sampling Theory. Englewood Cliffs NJ: Prentice Hall, Inc., 1967.

Related Sources

Blanchard, Benjamin S. Logistics Engineering and Management (Second Edition). Englewood Cliffs NJ: Prentice Hall, Inc., 1981.

BMDP Statistical Software (1983 Printing With Additions). Berkeley CA: University of California Press, 1983.

Air Force Logistics Command. Maintenance and Operational Data Access System Users Manual (Draft). Wright-Patterson AFB OH: HQ AFLC, 1 November 1984.

Department of the Air Force. Maintenance Data Collection System Users Manual. AFM 66-267. Washington: HQ USAF, 1 October 1979.

-----. Maintenance Management and Policy. AFR 66-1. Washington: HQ USAF, 21 April 1983.

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Captain Robert A. Heinlein was born on 20 September 1953 in Rockville Centre, New York. He graduated from high school in Mineola, New York, in 1971 and attended the Stevens Institute of Technology from which he received the degree of Bachelor of Engineering in May 1975. Upon graduation, he received a commission in the USAF through the ROTC program. He was called to active duty in February 1976. He completed Undergraduate Navigator Training and earned wings in October 1976. He then served as a C141A navigator in the 6th Military Airlift Squadron, McGuire AFB, New Jersey until April 1980, and as a C5A instructor navigator in the 3rd Military Airlift Squadron, Dover AFB, Delaware until May 1984. While assigned to Dover AFB, Captain Heinlein also served as an executive officer for the Wing and Vice Wing Commanders. In addition, in June 1983, he was awarded the degree of Master of Business Administration from the Southern Illinois University at Edwardsville. He entered the School of Systems and Logistics, Air Force Institute of Technology, in May 1984.

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This ~~study~~ explores the feasibility of using statistical sampling techniques in lieu of a census to collect Air Force maintenance (MDC) data. A practical sampling methodology is identified and the sample size required to collect data with a specified degree of statistical precision is illustrated. The variable cost of MDC data collection and processing is also identified. Using the F-16A Fire Control System on the aircraft at one base as an example, the potential cost and effort savings resulting from sampling are evaluated.

The sampling concept is based on a simple random sample of aircraft, by serial number, with full data collected on all aircraft in the sample. The sampling plan is designed to estimate the base level monthly total unscheduled maintenance manhours at the two digit work unit code level, with 10 percent relative precision and 90 percent confidence. The methodology used to estimate the variable cost of collecting and processing MDC data records is limited to base and Air Force Logistics Command (AFLC) levels. Base level costs considered are the opportunity cost of a maintenance technician's time to enter one MDC record into an automated system terminal, and the cost of computer processing and transmission of data to AFLC. AFLC costs considered are the machine time charges assessed against the DO56 Product Performance System.

In the single system studied, the variability in monthly unscheduled manhours per aircraft was found to be high. The resulting sample size required to estimate manhours with the desired degree of statistical accuracy, based on the greatest observed variability in historical data, nearly represents a census. The variable cost of collecting and processing MDC data is significant. However, unless a sophisticated technique can be used to predict data variability and reduce the required sample size, the potential cost and effort savings resulting from sampling appear to be minimal.

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